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SOME ASPECTS OF ESTIMATING THE PROBABILITY OF CLOUD-FREE LINES-OF-SIGHT IN DYNAMIC SITUATIONS

by

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Dynamic Cloud-Free Line-of-Sight (CFLOS) problems involve either moving points between which the line-of-sight is to be assessed or a time during which the line-of-sight between two points, moving or stationary, is to be assessed. There are no adequate assessment techniques available for these kinds of problems. As a preliminary step toward developing the required techniques, the variables associated with certain types of dynamic CFLOS problems are examined and a computer program which models the space/time aspects of these types is presented.

PREFACE

In April 1975, the Staff Meteorology Office of the Air Force Weapons Laboratory (AFWL/WE), working in conjunction with the Laser Systems Analysis Branch (AFWL/PGA), began a special project, "Weather Studies." The objective of this project was to determine the potential influence of the atmosphere and its associated phenomena on various airborne applications of laser devices. As the study progressed, the authors became increasingly interested in the problem of predicting the probability of a cloud-free line-of-sight (CFLOS) between two moving points. Although techniques were available for handling CFLOS questions of a static or instantaneous nature, it became apparent that these techniques were not designed to answer the kinds of questions being raised in "Weather Studies" and that new techniques were required.

The computer model presented herein is a preliminary step in developing the new techniques required to solve CFLOS questions involving a moving observer, moving observed point, and/or a time dimension. The major part of this investigation was performed by Ronald J. Nelson. The major part of the computer model was performed by Mead B. Wetherbe.

The authors gratefully acknowledge the constructive criticisms and support of their co-workers at AFWL. Thanks are due especially to Captains Steven Edelman, John King, and Carl Curatola for their valuable contributions during the development of the studies and analyses presented in this report.

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SOME ASPECTS OF ESTIMATING THE PROBABILITY OF CLOUD-FREE LINES-OF-SIGHT IN DYNAMIC SITUATIONS

SECTION A — INTRODUCTION

With the introduction of optical and infrared detection and tracking devices into the Department of Defense inventory, interest grew in developing methods for estimating the usability of such devices in the presence of clouds. One result of this interest was the development of various methods for predicting the probability of having a cloud-free line-of-sight (CFLOS) between two points. These methods, which have been available in various forms since the 1960s, provide tools for estimating CFLOS probabilities between a stationary observer and a stationary observed point at a specified elevation angle in the presence of a given amount of intervening clouds. None of these methods (e.g., Lund and Shanklin [1], McCabe [2], and Rapp, et al [3]) was designed to address CFLOS questions when moving observers, moving observed points, or time dimensions were involved. These kinds of questions are "dynamic CFLOS questions."

Many USAF applications, actual and potential, involve the use of optical or infrared systems on aircraft. Some applications might involve an airborne system, e.g., as a detector of a stationary target on the ground. In such a case one might wish to predict the probability that there will be a CFLOS between the detector and the target. A typical approach to this problem is to specify the altitude at which, and the range of depression angles within which, the system might operate. Then, given the climatological frequency distribution of cloud conditions for the area over which the system is to be employed, use some technique, such as that outlined in Rapp, et al., [3], to predict the probability of having a CFLOS between the two vehicles (points). Since at any instant the two points may be considered to be stationary, the approach seems reasonable for predicting the probability of an instantaneous CFLOS. Suppose, however, that one is interested not in some "instantaneous" CFLOS, but rather in a CFLOS which lasts for some finite time, on the order of one second. Or, suppose that both the observer and target are moving and that one wishes to predict the probability of a CFLOS lasting for some finite time between the two. The approach outlined above cannot handle these dynamic problems.

The remainder of this report presents the results of the work to date on dynamic CFLOS problems and makes available the computer model which we have used to gain insight into problems of this variety. It is by no means an exhaustive dissertation but the authors hope it can serve as a departure point for others interested in dynamic CFLOS problems.

SECTION B — DYNAMIC CFLOS PROBLEMS

Discussion of the Variables

One of the most important "variables" involved in dynamic CFLOS problems is the statement of the problem. The following problem is used as a basis for discussing the variables associated with dynamic CFLOS problems in general:

> Assume a vehicle B will be flying at a specific altitude and velocity over a specified area. A second, faster vehicle A will be introduced at an arbitrary initial slant range, azimuth, and elevation angle. The second vehicle will move on a straight-line course (Direct Intercept Course) designed to effect a collision with the first vehicle Given sufficiently detailed cloud information for the specified area, predict the probability that, at any time, a CFLOS will exist between the two vehicles for at least t units of time before the two vehicles reach a given slant-range separation.

The variables of the problem are as follows:

a. The initial positions of the two vehicles.

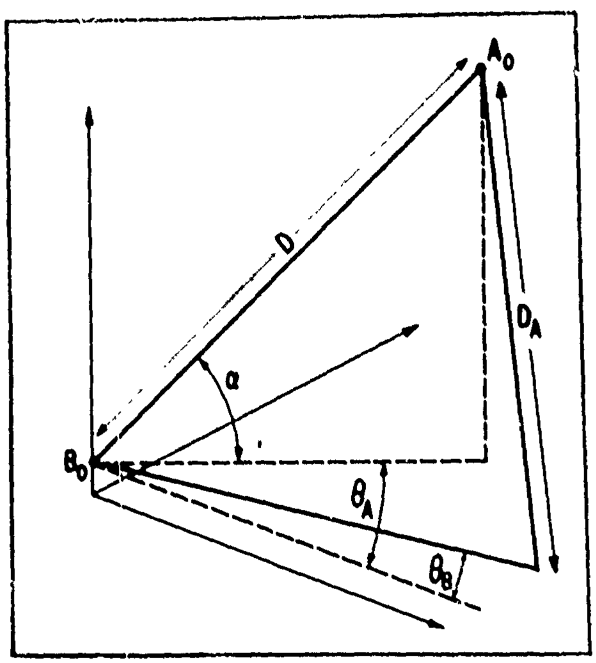
b. The relative speeds and paths of the vehicles.

c. The "boundary conditions" for the time duration (Δt) of the CFLOS and the final separation distance before which the specified CFLOS must occur.

d. The cloud characteristics for the area of interest.

Examination of the Relative Speeds and Paths

The first step in solving dynamic CFLOS problems is to determine the paths to be followed by the vehicles. Figure 1 depicts the geometry of the situation described above.



A_o, B_o: Initial positions of A and B

θ_A, θ_B: Initial azimuths of A and B

D : Initial slant range separating A and B

D_A: Distance A must travel to meet B

α : Elevation angle from B to A

Figure 1. Geometry of the Direct Intercept Course.

If V_A, V_B represent the speeds of A and B, respectively, then the relationship of D_A, the distance A must travel to meet B, to the other parameters (see Appendix A for details) is:

$$D_A = D \cdot F_2 \tag{1}$$

where

$$F_2 = \frac{-\frac{V_B}{V_A} F_1 \pm \left[\frac{V_B^2}{V_A^2} F_1^2 + 1 - \frac{V_B^2}{V_A^2}\right]^{\frac{1}{2}}}{1 - \frac{V_B^2}{V_A^2}} \tag{2}$$

and

$$F_1 = \cos \alpha \,(\cos \theta_A + \sin \theta_A \tan \theta_B) \cos \theta_B \tag{3}$$

B's total travel distance to the collision point (D_B) is directly proportional to A's and to the speed ratios involved. That is,

$$D_B = \frac{V_B D_A}{V_A} \tag{4}$$

Knowing the total distance involved, one can use direction cosines to determine the paired x,y,z positions of A and B in whatever time increments are desired. The paths, therefore, are defined.

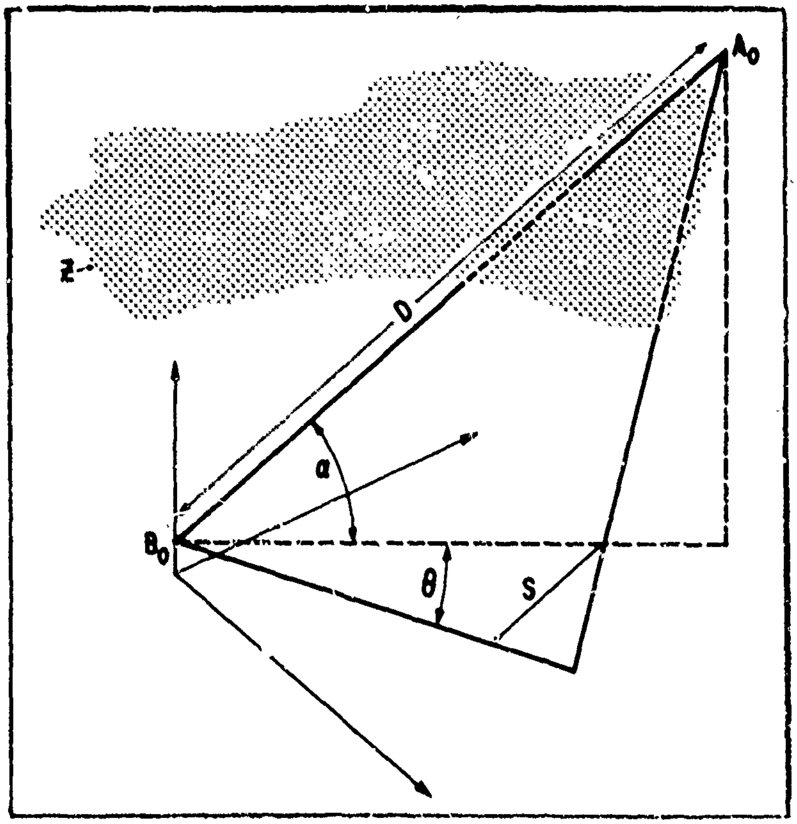
The Boundary Conditions for t and S

It would seem that one should now be able to specify the boundary conditions for the time duration of the CFLOS and the final separation distance of interest and using the detailed cloud information for the specified area, proceed with the CFLOS analysis. In the early stages of the study the authors proceeded in just that way, utilizing a randomly generated cloud field in the computer model as a substitute for the "detailed cloud information."

Fortunately, the program was written so that one could obtain a highly detailed output of the progress of the analysis. For a given set of cloud and boundary conditions, if B was repeatedly reset to its starting position and A was introduced at various azimuths, the ratio of free/obstructed lines-of-sight was almost always greater for approaches which came toward B from behind. The reason for this result will become apparent through an examination of the concept of a "critical cloud base."

Concept of a Critical Cloud Base

Figure 2 shows the geometry to be considered for this concept. A and B will again travel along straight lines with A following the direct intercept course.



A_o, B_o: Initial positions of A and B

D : Initial slant range separating A and B

α : Elevation angle from B to A

θ : Relative azimuth between A_o and B_o, ($\theta = |\theta_A - \theta_B|$)

Z : Cloud base height

Figure 2. Geometry of the Critical Cloud Base.

Consider the following problem:

> For the initial conditions specified (i.e., V_A/V_B, D, α, etc.), determine that height above the plane of B, (Z_C), above which the existence of clouds will have no effect on the probability of having a CFLOS for Δt units of time <u>at least once</u> before A and B approach within S of each other.

The detailed development given in Appendix B shows that

$$Z_C = Z - Z_B = \sin \alpha \left(S + \Delta t \frac{V_A}{F_2}\right) \qquad (5)$$

where Z_C is a critical relative cloud height so that if all clouds are based at $Z > Z_C + Z_B$, the required CFLOS will occur at least once. Equation (5) shows that one should not specify cloud characteristics for any model situation without considering the "boundary conditions" and dynamics of the situation.

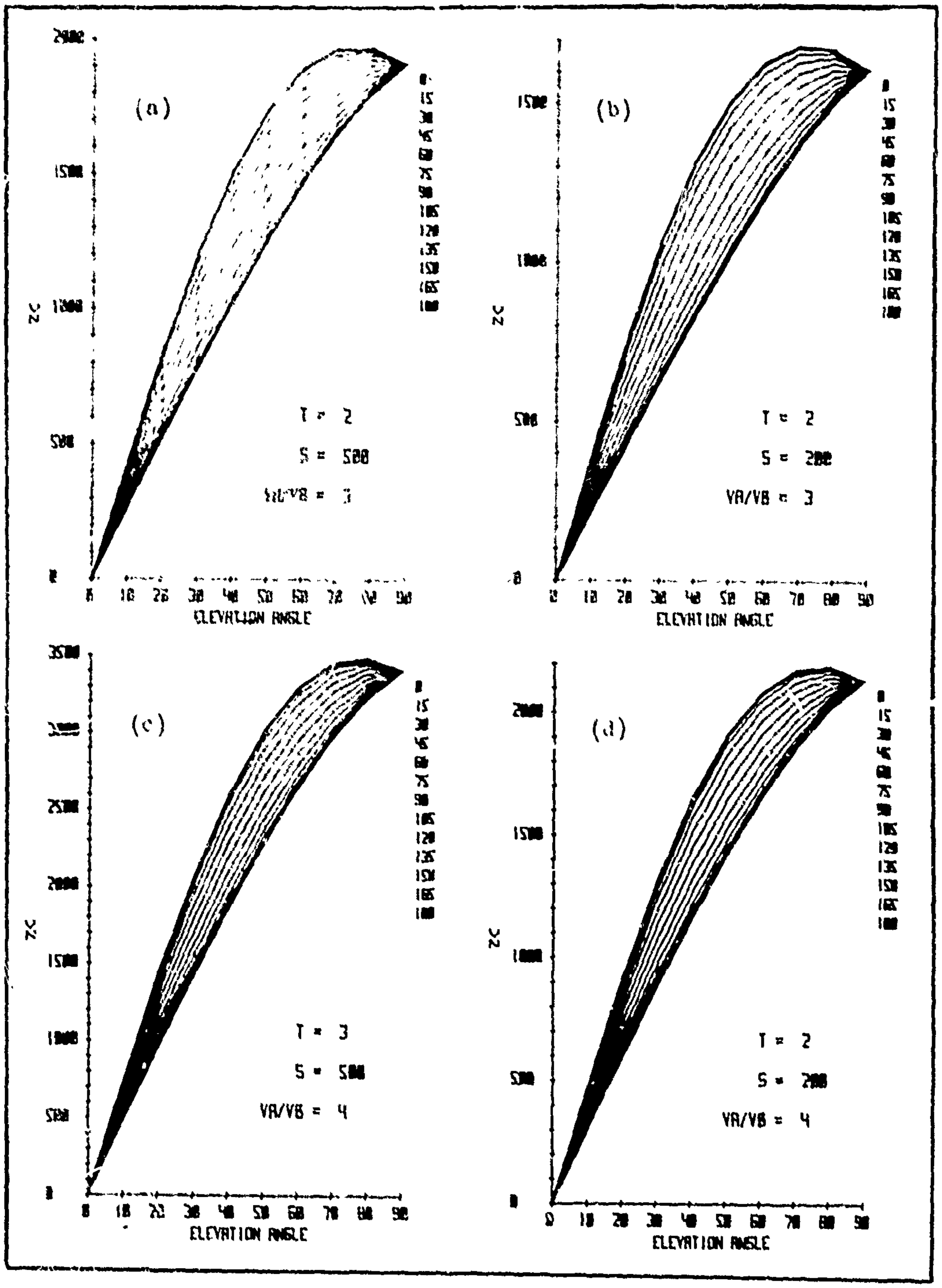


Figure 3. Variation of Z_c with Elevation Angle.

Figures 3 and 4 depict various ways of showing the functional relationships established in Equation (5). The V_B is 250 m/sec for all cases. The curves in Figure 3 are lines of constant relative azimuth; those in Figure 4 are lines of constant elevation angle. Figure 3(a), for example, shows that cloud bases at 1000 meters will insure at least one CFLOS lasting for 2 seconds (T). This CFLOS will occur before a slant-range distance (S) of 500 meters is reached by two vehicles

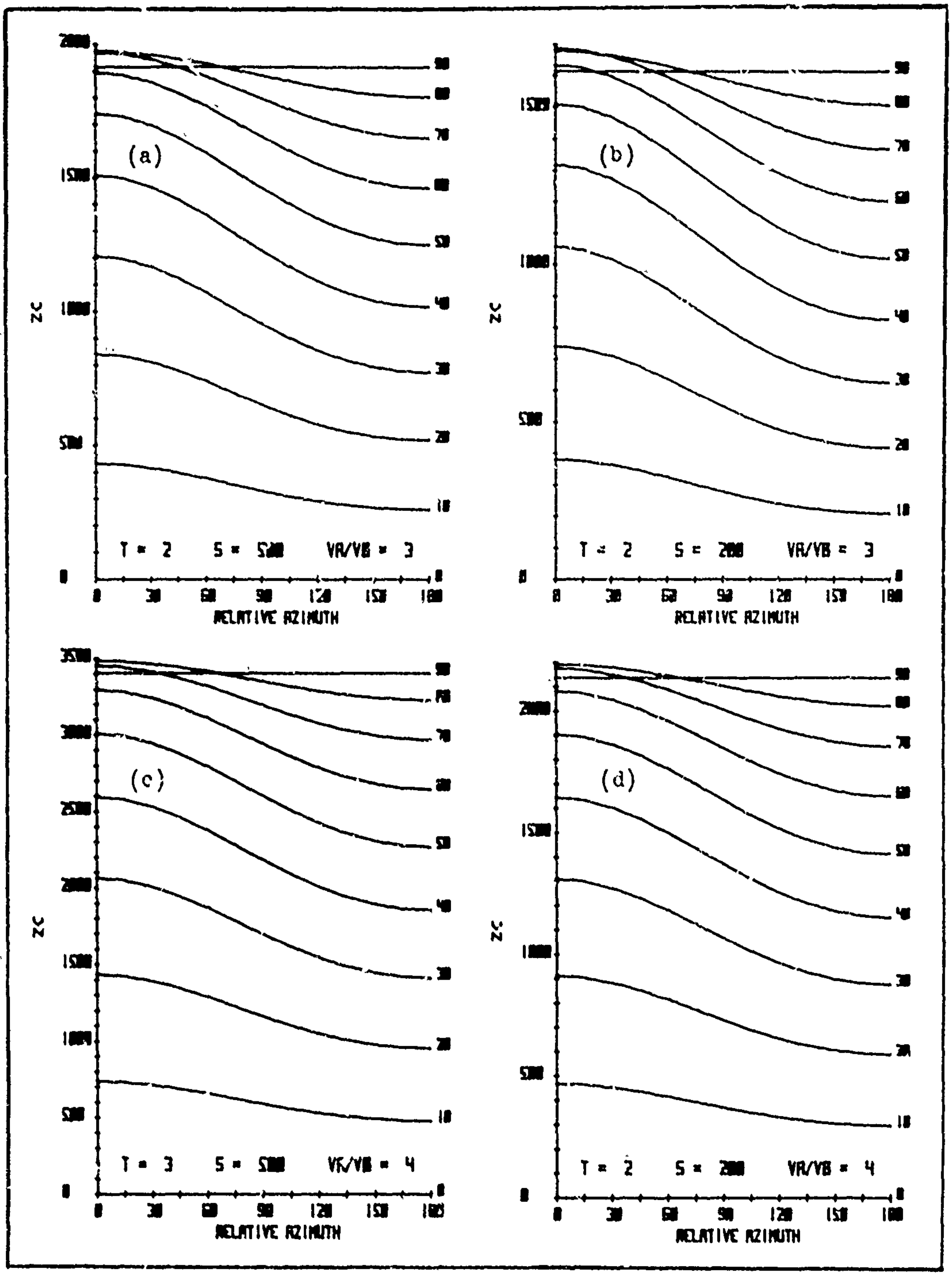


Figure 4. Variation of Z_C with Relative Azimuth.

travelling at a speed ratio (V_A/V_B) of 3 to 1, for all elevation angles less than about 24° at any relative azimuth. Similarly, 2000-meter cloud bases, for the conditions specified on Figure 3(d) will insure the required CFLOS for an elevation angle of 70° for relative azimuths of approximately $105° \leq \theta \leq 180°$. Note that the 0-180° relative azimuths can be "mirrored" into the 180°-260° azimuth range and that

"elevation angle" could as easily be interpreted as depression angle. As a result, Z_C can be treated as a cloud separation distance and therefore could be applied to cloud tops.

Figures 4(a) through 4(d) depict the variation of Z_C as a function of initial relative azimuth and elevation angle for various boundary conditions. The value of Z_C generally increases with increasing elevation angle and is higher for frontal than for rearward approaches. Note, however, that this generalization breaks down when the approach combines large elevation angles and small relative azimuths.

These variations should have a direct bearing on how one compiles the statistics in any modeled situation for a given cloud base. If, for example, the CFLOS probability statistics associated with a given elevation angle were grouped into a single value for all azimuths, that value would implicitly be weighted by the higher values associated with the rearward approaches. On the other hand, grouping the statistics at a given azimuth for all elevation angles would implicitly weight the answer by the higher values associated with the lower elevation angles. The physical reasons are apparent:

a. For a given elevation angle the closure rate is lower for large relative azimuths.

b. For a given azimuth the closure rate is lower for high elevation angles.

In either case the time available for CFLOS is higher for lower closure rates and therefore the probability of obtaining the CFLOS is higher (i.e., there is more opportunity).

The Cloud Characteristics

Simple logic dictates that there is a direct relationship between the probability of having a CFLOS and the probability of having those cloud conditions which preclude having a CFLOS. Predicting the probability of having a CFLOS, therefore, requires having "sufficiently detailed cloud information." This information must be merged with the other factors, e.g., dynamics and boundary conditions, involved in the problem.

For the problem being discussed, "cloud-base" is part of the required information. This report will show that information regarding the amount of sky covered at a particular altitude and the 3-dimensional geometry and spatial distribution of the individual elements will also be required. What is yet uncertain is the practical meaning of "sufficiently detailed" information and if, and how, that meaning changes as the problem variables change.

Historical records of surface-based weather observations can be used to obtain information regarding the probability that a particular sky coverage will be experienced at a particular altitude; the detail available, however, varies inversely with the altitude. Satellite data may eventually be useful in adding more detail at higher altitudes, but currently the information is limited to the lowest 8000 feet. Little or no information, and no information, and no historical records exist

relative to the "individual element" characteristics. Therefore, one must model the individual element characteristics and use historical data bases to obtain the sky cover.

The authors have yet to determine how best to utilize historical data since the sensitivity of answers to relatively unknown cloud-field characteristics, such as the distribution and 3-D geometry of the individual elements, are unknown. How will the interrelationship of cloud base and cloud cover as they relate to the dynamics of the problem, affect the answers? These are specific areas in which further analysis is required.

SECTION C — A DYNAMIC CFLOS COMPUTER PROGRAM

The computer program presented in Appendix D models a situation in which two points are separated in space in the presence of a cloud field to help study dynamic CFLOS problems. The lower point B begins moving from its initial position at a fixed heading and speed. The higher point A is introduced at a given vertical separation and slant range and a preselected azimuth to the right of B's path. Point A follows some path, usually the direct intercept course, and the line-of-sight between A and B is examined each 0.2 seconds of simulated time until a previously determined slant range is reached. B is then reset to its original position and the same process is repeated except that A approaches from the preselected azimuth to the left of B's path. B is then reset to its original position, a new heading is established 30° to the left of the original heading and the process starts anew. The scenario is repeated until a total of 12 headings (360°) have been examined. The "statistics" are then summarized for the 24 approaches involved.

<u>Some Limitations/Weaknesses of the Program:</u>

a. CLDNO, one of the two cloud models, represents a mid-continental, uniform-surface area, early-afternoon, summertime situation. This situation is relatively simple to model. CLDNO produces uniform circular elements, the centers of which are placed randomly in the X,Y plane. Coverage is determined by the X,Y projection of the individual elements onto the plane. The base height and thickness can be set but are uniform for all elements.

The random placement of the elements limits the total coverage in the application of the model. Theoretically, one could, by careful packing, achieve a coverage of about 78% (see Appendix C). In running the program, a practical limit is reached at about 45%. The program CLDOVR, developed because of this practical limit, allows for some restricted overlap of individual elements and seems to have a practical limit in coverage of about 70%. With larger fractional coverages the physical model more nearly represents a late afternoon situation but, because of the common tops used, is less than an adequate model. Modification of the model will continue to overcome the "coverage," "uniform top," and "single layer" limitations/weaknesses.

b. The coverage produced is not "sky-coverage" but rather "earth-coverage." The former requires a projection of the cloud elements against the celestial dome

while the latter is obtained by projecting the cloud bases against the assumed flat, underlying surface.

c. The chase models are limited in their applicability. For example, one would not use either model to simulate a "dog fight." Both models currently require that A be moving faster than B.

d. The assessment of the line-of-sight takes place every 0.2 seconds of simulated time. This time-step may be inappropriate for some applications (see Appendix B).

Questions Addressed by the Program

Given a particular set of conditions, the program is designed to answer three questions:

Question 1. What is the probability of having a CFLOS "at any instant?"

The line-of-sight between A and B is examined at each A,B position until A and B approach within S of each other. The number of times the line-of-sight is free of clouds (successes) is divided by the number of times it is examined (attempts). The results are accumulated for each of the 12 headings followed by B and printed out as the "static case" shown in Figure 5.

Question 2. What is the probability of having a CFLOS which lasts for at least t-units of time at any time?

A time, t, is chosen as an integral multiple of 0.2 seconds. That is, t=0.2N, where N-1,2,3,...M.* The first N-consecutive lines-of-sight are then examined for a continuous CFLOS. A record is made of the results of that examination. The first line-of-sight is then ignored and the next N-consecutive lines-of-sight are examined, etc. The number of times that N-consecutive lines-of-sight are cloud free divided by the number of times N-consecutive lines-of-sight are examined before S is reached, forms the basis for the answer to this question. The process is repeated for all B-headings and the collected statistics show up as "Probability of a CFLOS for the time indicated," with t, in seconds, following ".GE." in Figure 5.

Question 3. What is the minimum frequency of occurrence of a CFLOS lasting for at least t-units of time?

For each initial placement of A,B, a binary record is made of whether or not a CFLOS existed for t-units of time at least once. For any initial set of conditions and for a given cloud situation the maximum number of attempts would be 24; i.e., A approaches B from left and right aspects for each of 12 different headings used by B. During each chase, a CFLOS either did or did not exist at least once for t-units of time.

* For the limit of M, see Appendix B.

The output of this analysis is found in the Minimum frequency..." section of Figure 5.

```
 PROBABILITY OF A CFLOS - STATIC CASE-      .247
 PROBABILITY OF A CFLOS FOR AT LEAST THE TIME INDICATED
 .GE.1    .080          .GE.2    .007
 MINIMUM FREQUENCY OF OCCURRENCE OF A CFLOS FOR AT LEAST THE TIME INDICATED
ONE SECOND        6/24          TWO SECONDS        1/24


 ABOVE INFO BASED ON - BASE =   5.5,TOPS =  11.5 ,RADIUS =   4.0 ,COVERAGE =   .435

 PROBABILITY OF A CFLOS - STATIC CASE-      .228
 PROBABILITY OF A CFLOS FOR AT LEAST THE TIME INDICATED
 .GE.1    .053          .GE.2   0.000
 MINIMUM FREQUENCY OF OCCURRENCE OF A CFLOS FOR AT LEAST THE TIME INDICATED
ONE SECOND        5/24          TWO SECONDS        0/24


 ABOVE INFO BASED ON - BASE =   5.5,TOPS =  14.5 ,RADIUS =   4.0 ,COVERAGE =   .435

 PROBABILITY OF A CFLOS - STATIC CASE-      .356
 PROBABILITY OF A CFLOS FOR AT LEAST THE TIME INDICATED
 .GE.1    .121          .GE.2    .007
 MINIMUM FREQUENCY OF OCCURRENCE OF A CFLOS FOR AT LEAST THE TIME INDICATED
ONE SECOND       10/24          TWO SECONDS        1/24


 ABOVE INFO BASED ON - BASE =   7.0,TOPS =  14.5 ,RADIUS =   4.0 ,COVERAGE =   .435

 PROBABILITY OF A CFLOS - STATIC CASE-      .356
 PROBABILITY OF A CFLOS FOR AT LEAST THE TIME INDICATED
 .GE.1    .121          .GE.2    .007
 MINIMUM FREQUENCY OF OCCURRENCE OF A CFLOS FOR AT LEAST THE TIME INDICATED
ONE SECOND       10/24          TWO SECONDS        1/24


 ABOVE INFO BASED ON - BASE =   7.0,TOPS =  18.3 ,RADIUS =   4.0 ,COVERAGE =   .435

 PROBABILITY OF A CFLOS - STATIC CASE-      .319
 PROBABILITY OF A CFLOS FOR AT LEAST THE TIME INDICATED
 .GE.1    .174          .GE.2    .097
 MINIMUM FREQUENCY OF OCCURRENCE OF A CFLOS FOR AT LEAST THE TIME INDICATED
ONE SECOND        9/24          TWO SECONDS        3/24


 ABOVE INFO BASED ON - BASE =   4.0,TOPS =   9.0 ,RADIUS =   3.0 ,COVERAGE =   .245

 PROBABILITY OF A CFLOS - STATIC CASE-      .278
 PROBABILITY OF A CFLOS FOR AT LEAST THE TIME INDICATED
 .GE.1    .136          .GE.2    .069
 MINIMUM FREQUENCY OF OCCURRENCE OF A CFLOS FOR AT LEAST THE TIME INDICATED
ONE SECOND        8/24          TWO SECONDS        2/24


 ABOVE INFO BASED ON - BASE =   4.0,TOPS =  11.5 ,RADIUS =   3.0 ,COVERAGE =   .245
```

Figure 5. Sample Output of the Program.

Some Model Results

Figures 6a and 6b show scaled drawings of one quadrant of a cloud field generated by CLOUDNO. The light dashed lines represent B's path, which is actually at a height which is below the cloud base. The heavy dashed lines are the projections of A's path into the plane of B. The heavy solid lines are the actual paths followed by A. See Appendix D for a brief description of the HUNT and HUNTD chase models. In effect then, Figures 6a and 6b are pictures of a "run." The lines-of-sight which are examined are those lines which would connect the positions of A and B at any time.

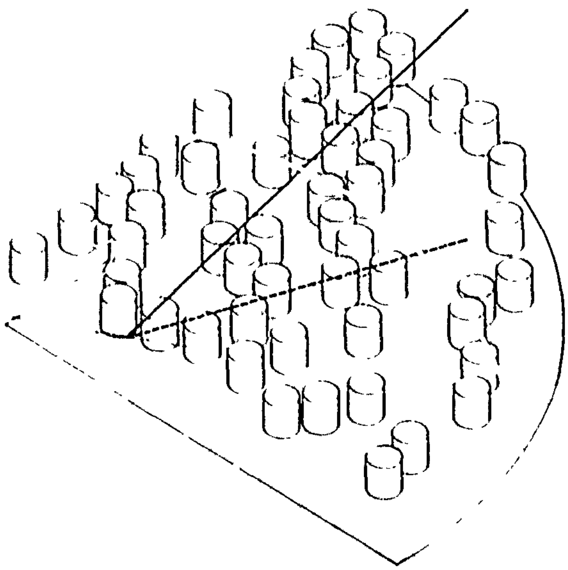


Figure 6a. A Visual Representation of CLOUDNO and HUNTD.

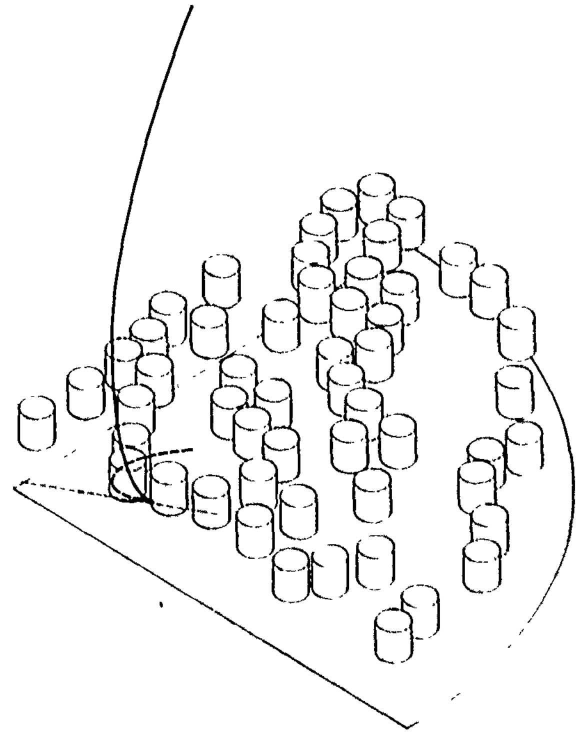


Figure 6b. A Visual Representation of CLOUDNO and HUNT.

Table 1 presents the statistics associated with many such runs. The three sets of statistics presented in the table are related to those questions discussed in the previous section. For a given run there are approximately 600 "instantaneous-attempts" and 450-550 one-second "dynamic-attempts." The "minimum frequency" values cannot exceed 24 since there are only 24 opportunities per run for having a CFLOS for the time span indicated at least once. There is, of course, only one value of "earth-cover" for a given run.

The two sets of statistics associated with A and E were derived from the same 22 nonoverlapping cloud distributions. The distributions were established based on a 400-meter cloud radius. Since the cloud elements do not overlap, one could simply change the radius and calculate the new coverage. Most of the data associated with the B and F statistics are derived from these same distributions by simply changing the thickness of the cloud elements. About one-half of the C and D statistics use

Table 1. CFLOS Probabilities for Various Modeled Cloud Situations when $V_A/V_B = 4$, $V_B = 250$ m/sec, $S = 501$ meters, $Z_B = 150$ meters, and $\sigma \simeq 22°$.

							Cloud-Free Line-of-Sight Results					
							Pr (Instantaneous)		Pr (Dynamic) t > 1 sec		Min. Frequency of Occurrence/Run t = 1 sec	
Case	No. of Runs	Cloud Data (meters) Base	Top	Radius	Earth Cover $\bar{x}$	Sx	$\bar{x}$	Sx	$\bar{x}$	Sx	$\bar{x}$	Range
A	22	400	900	400	.47	.02	.15	.04	.04	.03	2.9	0-6
B	18	400	1400	400	.48	.02	.13	.03	.02	.02	2.1	0-4
C	10	800	1900	400	.48	.02	.41	.02	.18	.03	23.9	23-24
D	8	550	1600	400	.48	.02	.21	.03	.03	.02	3.5	2-5
E	22	400	900	300	.27	.01	.32	.06	.18	.07	7.8	4-10
F	18	400	1400	300	.27	.01	.25	.04	.11	.04	6.7	1-8

Where $\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i$ and $Sx = \left[\frac{\sum_{i=1}^{N} x_i^2 - N \bar{x}^2}{N-1} \right]^{\frac{1}{2}}$

Range: x_i minimum value to x_i maximum value

these distributions, so there are, at most, 30 different cloud element distributions; certainly not a representative sample of the infinite variety of distributions which could be produced either in the real world or in the model. Nonetheless, Table 1 can be used to gain insight into dynamic CFLOS problems.

The content of Table 1 is associated with a very specific set of parameters; i.e., specific values for V_B, Z_B, V_A/V_B, S, and α. The authors wish to stress the point: Dynamic CFLOS problems tend to be complex and unique and it will be difficult to generalize solutions for large ranges of the associated parameters.

The "Earth-Cover" for Cases A, B, C, and D are essentially the same. Examination of the associated "instantaneous" and "dynamic" probabilities indicates that the values may be more sensitive to changes in cloud-base height than to changes in cloud thickness. This sensitivity relationship is even more evident in the "Minimum Thickness..." data. Comparing E and F to C leads to the tentative conclusion that, at least for some combinations of decreased-coverage/increased-cloud-base, the latter will be the more significant. Finally, the probability of having a finite-time CFLOS is less than the probability of having a CFLOS instantaneously. This follows from the fact that a low instantaneous value indicates a frequently obscured line-of-sight.

Experience indicates that the distribution of the individual elements is a significant variable and that its significance increases as earth-coverage decreases. This seems to be particularly true for earth-coverage less than about 40%. The authors also tend to believe that, for a given coverage, "cloud radius" is not a significant variable; although the elements are smaller, they are more numerous and the increased population effectively cancels the effect of the decreased size.

Changes in V_A/V_B are significant, as can be seen by a comparison of Table 1 and Table 2. The same specific parameters are used for both tables except that, in Table 2, $V_A/V_B = 3$, and 10 completely different distributions were used. Case 1 of Table 2 and Case A of Table 1 differ only slightly in mean earth-coverage and may be compared directly. Being cautious to note the differences in cloud characteristics, one may also compare Case 2 to Cases C and D, and Case 3 to Cases E and F. The generally higher values of Table 2 would seem to stem primarily from the lower speed ratios; but one must be cautious of such a generalization.

Table 2. CFLOS Probabilities for Various Modeled Cloud Situations when $V_A/V_B = 3$, $V_B = 250$ m/sec, $S = 501$ meters, $Z_B = 150$ meters, and $\alpha \approx 22°$.

	Cloud Data				CFLOS Results		
Case	Base	Top	Radius	Mean Earth-Cover	Pr (Instantaneous)	Pr (Dynamic) $t \geq 1$	Min. Freq. of Occurrence $t = 1$
1	400	900	400	.44	.19	.08	5.1
2	700	1450	400	.44	.37	.18	24
3	400	1150	400	.25	.29	.15	11

Table 3 presents selected calculations of Z_C which can be used to help interpret the statistics of Tables 1 and 2. (Linear interpolation of the values will be accurate to within about 1%.) For the conditions in Table 1, $Z_C \simeq 548$ meters. Since Z_B for Tables 1 and 2 was 150 meters, any cloud base above 698 meters for Table 2, or above 795 meters for Table 1, would assure a CFLOS for one-second at least once. Therefore, the minimum frequency values of Case C and Case 2 are essentially predictable a priori. Note also that if A approaches B from behind with a relative azimuth of 165° $V_A/V_B = 3$, $\alpha \leq 20°$, the minimum frequency column of Case D could be "predicted" (i.e., calculated) a priori.

Table 3. Z_C Values for Selected Conditions
V_B = 250 m/sec, t = 1 sec, S = 501 meters.

Elev. Angle	Speed Ratio: $V_A/V_B = 3$						Speed Ratio: $V_A/V_B = 4$					
	Initial Relative Azimuth											
	15°	30°	45°	165°	150°	135°	15°	30°	45°	165°	150°	135°
10°	258	252	244	175	178	183	301	296	288	219	222	227
20°	503	492	476	347	353	363	589	579	564	434	440	450
30°	723	710	688	514	522	535	850	837	817	641	649	664

SECTION D — SUMMARY AND CONCLUSIONS

Current techniques for predicting the probability of a CFLOS are designed for problems which are instantaneous in nature and involve stationary points. Dynamic CFLOS problems involve either the movement of one, or both, of the points between which the line-of-sight is to be assessed or a time during which the line-of-sight is to be assessed, or both movement and time may be involved. Hence, current CFLOS prediction techniques can not be used for dynamic CFLOS problems. To assess the potential usability of those airborne electro-optical systems which are effectively blocked by clouds, new techniques must be developed. "Modeling" is the approach which the authors have used as a preliminary step in that direction.

The computer program discussed herein indicates that dynamic CFLOS problems tend to be complex, unique, and not amenable to generalization. To solve a dynamic CFLOS problem one requires a detailed knowledge of the initial positions and subsequent velocities of the two points between which the line-of-sight is to be assessed, detailed knowledge of the boundary conditions related to the space/time dimensions of the problem, and detailed knowledge of the cloud field characteristics, including the 3-dimensional geometry and spatial distribution of the individual cloud elements. The dynamics of a problem might be definable through a knowledge of the operational characteristics of the aircraft involved. The boundary conditions and time increments to be used in the line-of-sight assessment might stem from the characteristics of the electro-optical system. These are, essentially, nonmeteorological problems. The meteorologist will have to define the cloud field characteristics.

Practically speaking, extensive knowledge of the required cloud field characteristics is limited to "cloud amount vs altitude" and even that is limited, essentially, to the lowest 8000 feet. Satellite data may be useful in extending our knowledge of this parameter at higher altitudes. Detailed information relative to the geometry and spatial distribution of the individual elements is extremely limited to nonexistent. To determine what degree of resolution will be required and how much intelligence can be derived from historical records will require further insight into the nature of dynamic CFLOS problems and further analysis of the data base.

The computer program presented herein can be a useful tool in developing insight into the variables associated with dynamic CFLOS problems. In particular, it can be used to examine the sensitivity of the answers to changes in the input parameters. Being careful to observe the artificiality of the model, it can also be used to obtain what might best be termed "ball-park" estimates of real world situations. For example, for situations similar to those discussed in this report, it would seem that the probability of having a cloud-free line-of-sight, either instantaneously or for as short a period as one second, will be low even in fair-weather conditions.

SECTION E — REFERENCES

[1] Lund, I. A. and Shanklin, M. D.: "Universal Methods for Estimating Probabilities of Cloud-Free Lines-of-Sight Through the Atmosphere," J. Appl. Meteorol., Vol. 12, 1973, pp. 28-38.

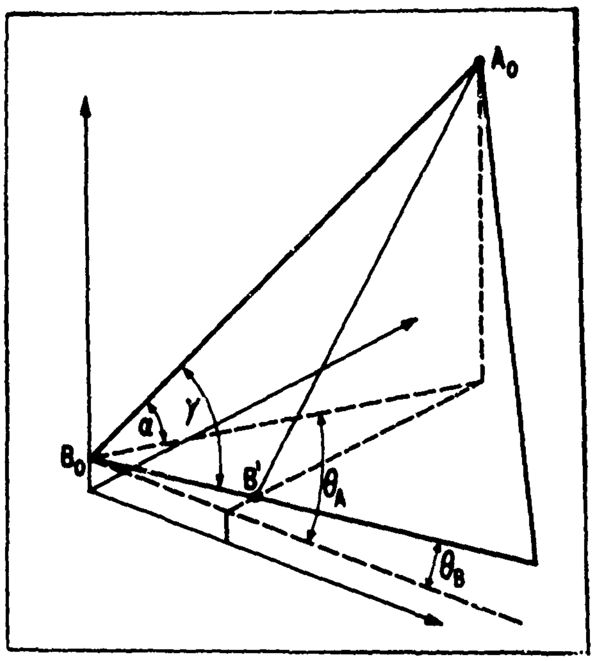
[2] McCabe, J. T.: "Estimating Mean Cloud and Climatological Probability of Cloud-Free Line-of-Sight," AWSTR 186, Air Weather Service, Scott AFB, IL., 1965, 26 p.

[3] Rapp, R. R., et al.: "Cloud-Free Line-of-Sight Calculations," J. Appl. Meteorol., Vol. 12, 1973, pp. 484-493.

Appendix A

DIRECT INTERCEPT MODEL

Problem: Given the initial positions and speeds of A and B and a level route of flight at known azimuth for B, find the distance A must travel to intercept B.



A_o, B_o = Initial positions of A and B

α = Elevation angle from B_o to A_o

θ_B = Azimuth of the path to be traversed by B

θ_A = Azimuth of A_o

γ = Angle between $\overline{A_oB_o}$ and $\overline{B_oB'}$

Figure A-1. Direct Intercept Model.

Let the following definitions apply:

(X_A, Y_A, Z_A), $(0, 0, Z_B)$: x, y, z coordinates of A_o and B_o

C : Distance $\overline{A_oB'}$

D : Distance $\overline{A_oB_o}$

D_A, D_B : Distance to be traveled by A and B

V_A, V_B : Constant speeds of A and B

Begin by solving for Cos γ. From Figure A-1 and the definitions given,

$$Y_A = D \cos \alpha \sin \theta_A \tag{A-1}$$

$$X_A = D \cos \alpha \cos \theta_A \tag{A-2}$$

$$\overline{B_oB'} = X_A \sec \theta_B \tag{A-3}$$

From the law of cosines we have:

$$C^2 = D^2 + (\overline{B_oB'})^2 - 2D\,(\overline{B_oB'})\,\text{Cos}\ \gamma$$

and, substituting from Equation (A-3)

$$C^2 = D^2 + X_A^2\ \text{Sec}^2\ \theta_B - 2DX_A\ \text{Sec}\ \theta_B\ \text{Cos}\ \gamma \tag{A-4}$$

But, note that

$$C^2 = (Z_A - Z_B)^2 + (Y_A - X_A\ \text{Tan}\ \theta_B)^2 \tag{A-5}$$

Hence, one can set Equation (A-4) equal to Equation (A-5), carry out the multiplication indicated in the second term of the right side of Equation (A-5), and rearrange and combine terms to obtain

$$\text{Cos}\ \gamma = \frac{X_A + Y_A\ \text{Tan}\ \theta_B}{D\ \text{Sec}\ \theta_B} \tag{A-6}$$

Substituting Equations (A-1) and (A-2) for Y_A and X_A, respectively, and rearranging and simplifying terms results in the equation

$$\text{Cos}\ \gamma = \text{Cos}\ \alpha\ (\text{Cos}\ \theta_A + \text{Sin}\ \theta_A\ \text{Tan}\ \theta_B)\ \text{Cos}\ \theta_B \tag{A-7}$$

which will be generalized for use as

$$\text{Cos}\ \gamma = F_1 \tag{A-8}$$

By definition, $D_A = V_At$ and $D_B = V_Bt$. Therefore,

$$D_B = D_A\,\frac{V_B}{V_A} \tag{A-9}$$

From the law of cosines we have:

$$D_A^2 = D^2 + D_B^2 - 2DD_B\text{Cos}\ \gamma \tag{A-10}$$

Substituting from Equations (A-8) and (A-9) and rearranging terms

$$D_A^2\left(1 - \frac{V_B^2}{V_A^2}\right) + 2D_AD\,\frac{V_B}{V_A}\,F_1 - D^2 = 0 \tag{A-11}$$

from which, using the general solution to quadratic equations, and requiring that $V_B \neq V_A$,

$$D_A = D\left[\frac{-\dfrac{V_B}{V_A}F_1 \pm \sqrt{\dfrac{V_B^2}{V_B^2}F_1^2 + 1 - \dfrac{V_B^2}{V_A^2}}}{1 - \dfrac{V_B^2}{V_A^2}}\right] \tag{A-12}$$

Or, for $V_B = V_A$

$$D_A = \frac{D}{2F_1} \tag{A-13}$$

and, physically, only the positive radical of Equation (A-12) applies.

In the text the problem was stated assuming $V_A > V_B$. The computer program currently requires that V_A be greater than V_B. However, Equations (A-12) and (A-13) clearly indicate that D_A has solutions which are not restricted by $V_A > V_B$. Three possibilities will be examined: $V_A = V_B$, $V_A > V_B$, and $V_A < V_B$.

Case 1: $V_A = V_B$

From Equation (A-8), the range of F_1 is: $-1 \leq F_1 \leq 1$. Physical reasoning dictates that $F_1 < 0$ be eliminated since A cannot overtake B when approaching from behind B's initial position. Therefore, only $0 \leq F_1 \leq 1$ is considered.

From Equation (A-13) and the definition of F_1

$$\frac{D}{D_A} = 2 \text{ Cos } \gamma \tag{A-14}$$

from which solutions may be obtained when $V_A = V_B$ for all choices of γ such that $\frac{3\pi}{2} < \gamma < \frac{\pi}{2}$.

Now examining $\frac{V_B}{V_A} = K$ where $K \neq 1$ and using Equation (A-12), we obtain

$$D_A = D \left[\frac{-KF_1 \pm \sqrt{K^2 (F_1^2 - 1) + 1}}{1 - K^2} \right] \tag{A-15}$$

Given that $K \neq 1$, Equation (A-15) only requires that

$$K^2 (F_1^2 - 1) \geq -1 \tag{A-16}$$

Clearly any negative contribution must come from $F_1^2 - 1$. This dictates that K^2 must be restricted to certain maximum values to insure that the condition of Equation (A-16) is not violated. Table A-1 and Figure A-2 illustrate the values as a function of γ for the range $0 \leq \gamma < 90°$.

Tables A-1. Maximum K-Values.

K_{MAX}	∞	5.75	2.92	2.00	1.56	1.31	1.15	1.06	1.02
γ	0	10	20	30	40	50	60	70	80

Case 2: $V_A > V_B$

For this case $K < 1$ and therefore the condition imposed by Equation (A-16) is always met.

Case 3: $V_A < V_B$

For this case $K > 1$ and therefore K must be restricted to the range $1 < K < K_{max}$

Finally,

$$D_A = DF_2 \qquad \text{(A-17)}$$

where F_2 is defined according to the following:

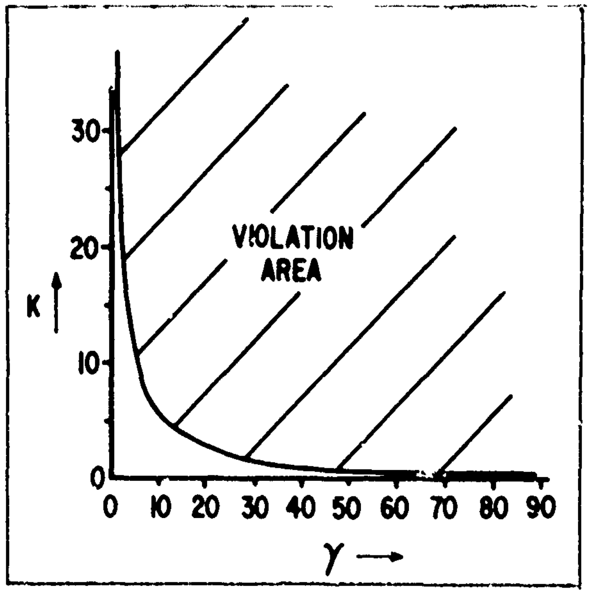


Figure A-2. Violation Area for K and γ.

Case 1: $F_2 = \frac{1}{2F_1}$ when $V_A = V_B$

Case 2:

$$F_2 = \frac{-\frac{V_B}{V_A} F_1 + \sqrt{\frac{V_B^2}{V_A^2} F_1^2 + 1 - \frac{V_B^2}{V_A^2}}}{1 - \frac{V_B^2}{V_A^2}} \quad \text{when } V_A > V_B$$

Case 3:

$$F_2 = \frac{-KF_1 + \sqrt{K^2 (F_1^2 - 1) + 1}}{1 - K^2}$$

subject to both of the following conditions:

a. $K^2 (F_1^2 - 1) \geq -1$

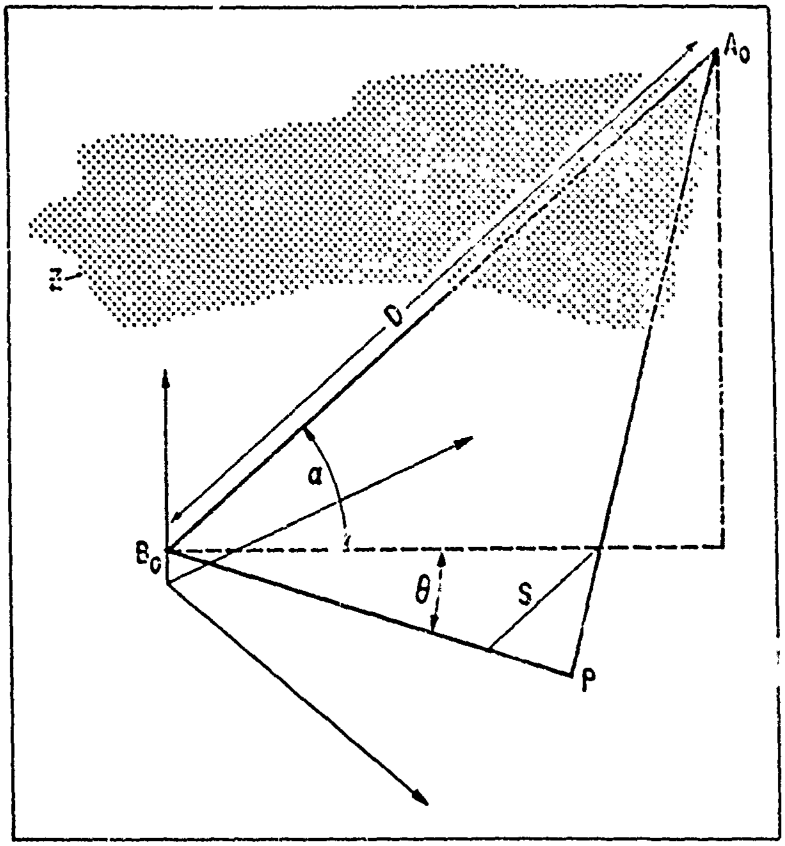
b. $K > 1$

Note that Case 2 is the case discussed in the text.

Appendix B

ANALYSIS OF THE CRITICAL RELATIVE CLOUD BASE

Problem: Determine the height, Z_C, above the plane of B, above which the existence of clouds will have no effect on the probability of having a CFLOS between A and B for Δt units of time at least once before A and B approach within distance S of each other, given that A pursues B in accordance with the direct intercept model.



θ : Azimuthal separation of A_o and B_o (relative azimuth)

α : Elevation angle from B_o to A_o

D : Distance $\overline{A_oB_o}$

Z : Base height of the lowest layer of clouds

P : Intersection of the paths of A and B

Figure B-1. Critical Cloud Base.

Let the following definitions apply:

A_o, B_o, D, D_A, D_B, Z_A, Z_B: As defined in Appendix A

δ : Angle between $\overline{A_oP}$ and $\overline{Z_AZ_B}$

L_C: Distance from A_o to Z along the path of A

L : Distance from the intersection of A's path with the plane of Z to that point where A and B come within distance S of each other

L_S^A, L_S^B: Distances which have yet to be traveled by A and B from that point where A and B are within distance S of each other to the point P.

Noting from the definitions that:

$$D_A = L_C + L_S^A + L$$

and therefore

$$\frac{L}{V_A} = \frac{D_A - L_C - L_S^A}{V_A} \tag{B-1}$$

and

$$\text{Cos } \delta = \frac{Z_A - Z}{L_C} = \frac{Z_A - Z_B}{D_A}$$

from which

$$L_C = D_A \left(\frac{Z_A - Z}{Z_A - Z_B}\right) \tag{B-2}$$

From similar triangles

$$L_S^A = \frac{S\ D_A}{D} \tag{B-3}$$

By definition, $\Delta t = \frac{L}{V_A}$. Combining this with Equations (B-1), (B-2), and (B-3), we obtain:

$$\Delta t = \frac{D_A}{V_A} \left(1 - \frac{Z_A - Z}{Z_A - Z_B} - \frac{S}{D}\right)$$

from which

$$Z = Z_B + (Z_A - Z_B) \left(\frac{S}{D} + \frac{\Delta t V_A}{D_A}\right) \tag{B-4}$$

Hence the cloud base relative to the height of B is

$$Z_C = Z - Z_B = (Z_A - Z_B) \left(\frac{S}{D} + \frac{\Delta t V_A}{D_A}\right) \tag{B-5}$$

Substituting from Equation (A-17), Appendix A, for D_A yields

$$Z_C = (Z_A - Z_B) \left(\frac{S}{D} + \frac{\Delta t V_A}{D\ F_2}\right)$$

and, since $(Z_A - Z_B) = D \text{ Sin } \alpha$

$$Z_C = \text{Sin } \sigma \left(S + \frac{\Delta t V_A}{F_2}\right) \tag{B-6}$$

Hence, given V_A and the definition of F_2 (see Appendix A), one can choose a slant range (S) and Δt of interest and calculate the height above which cloud bases will have no impact on the probability of having a CFLOS between A and B at least once before A and B approach within S of each other.

Clearly, Δt will not be meaningful unless it is chosen such that

$$\Delta t \le \frac{D_A}{V_A}$$

and therefore

$$\Delta t \le \frac{DF_2}{V_A} \tag{B-7}$$

In the analysis procedure described in the text Δt is treated as

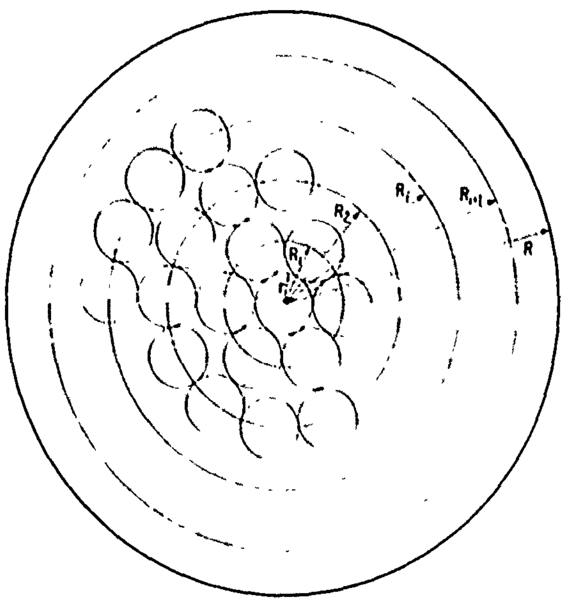
$$\Delta t = gN$$

where g is the incremental time-step used in the analysis of the line-of-sight and N has a maximum value of M such that the total time involved in the chase is not exceeded. Clearly, g only makes sense when it is some fraction of Δt, but what fraction should it be? A value of 0.2 seconds was chosen for the program based on a subjective analysis of the interrelationship of the cloud characteristics (radius and thickness) and the speeds typically involved. The authors have not yet examined the sensitivity of the results to changes in "g-values" but this, too, is an area which needs study. In any case, one should not choose g completely arbitrarily.

Appendix C

CLOUD-COVER LIMITATION OF A UNIFORM DISTRIBUTION MODEL

Problem: Determine the maximum fractional coverage obtainable from placing uniform circular elements into the large circular area such that each element is totally contained within the larger area and no elements overlap.



r = Radius of cloud elements

R = Radius of entire area

R_i = Radius of i^{th} locus of cloud centers where

$$R_i < R_{i+1}$$

Figure C-1. A Uniform Distribution Model.

Let the following definitions apply:

L_i = Circumference of i^{th} locus

N_i = Number of elements on L_i

N = Total number of elements

i_{max} = Maximum number of loci

Case 1: Condition $0 < r << R$

The circumference of the i^{th} locus is

$$L_i = 2\pi R_i \tag{C-1}$$

The radius of the i^{th} locus is

$$R_i = 2ri \tag{C-2}$$

therefore $L_i = 4\pi ri$

If the number of elements on a given locus must be an integral value, then

$$N_i \leq 2\pi i \tag{C-3}$$

The maximum number of loci which can be allowed for a given cloud radius will be $\frac{R}{2r}$.

From Equation (C-2), we note that a hole of radius r has been left at the center of the area. Hence, if $\frac{R}{2r} = K$, and K is truncated to an integer, then $i_{max} = k-1$ and

$$N \leq 1 + \sum_{i=1}^{K-1} N_i$$

and from $N_i \leq 2\pi i$

$$N \leq 1 + 2\pi \sum_{i=1}^{K-1} i \tag{C-4}$$

and testing various values of K, the authors found that

$$N \leq 1 + \pi K(K-1) \tag{C-5}$$

The fraction of the area covered by clouds is

$$F = \frac{N\pi r^2}{\pi R^2} = \frac{Nr^2}{R^2}$$

and therefore

$$F \leq \frac{1 + \pi K(K-1)}{4K^2}$$

Finally, we note

$$\lim_{k \to \infty} F = \frac{\pi}{4} \approx .7854$$

In practice, the authors have observed that randomly placed elements, which are not allowed to overlap, rarely exceed 50% coverage.

Case 2: $0 < r < R$

The solution of $r = F$ and $N = 1$ with the element centered at the center of the circle is a trivial but valid solution. Another solution is $\sqrt{\frac{\pi}{4}}\, R$ for which $F = \frac{\pi}{4}$. Hence, one can obtain fractional coverage in excess of $\frac{\pi}{4}$ for a single element centered at the center of the circle whose radius meets the condition

$$R \sqrt{\frac{\pi}{4}} < r < R$$

Appendix D

LISTING OF A DYNAMIC CFLOS COMPUTER PROGRAM

The computer program discussed herein can be thought of in terms of two separate, but relatable, parts: Driver programs and subroutines. Driver programs are used to define the values which the variables are to have in the subroutines and to model the "evolution" of the dynamic encounters. The currently modeled evolution for all driver programs is as described in Section C of this report. Alternative models might call for a single azimuthal approach (e.g., 15° to the left of B, as a single choice), but repeated with higher resolution (e.g., reanalysis for incremental changes of 10° in B's heading). A better understanding of the overall program can be obtained by operating one of the driver programs described below.

Driver Programs

BCFLOS A basic driver program which utilizes a nonoverlapping cloud field, a direct intercept chase model and azimuthal variations of ± 25° from B's heading. Summaries are made of the line-of-sight statistics collected for the 12 headings taken by B. BCFLOS could be run with an overlapping cloud-field. (Table D-1.)

LOSØAZ A somewhat more involved program which is to be used only with a nonoverlapping cloud-field. Reanalysis of the line-of-sight is performed as changes are introduced in cloud base, thickness, and radius values, for a given cloud-element distribution. (Table D-2.)

LOS1AZ A program designed specifically for the overlapping cloud-field. Users will note that the only significant difference between LOSØAZ and LOS1AZ is that in the latter, the cloud-radius is not varied. (Table D-3.)

Subroutines

Comment cards have been inserted liberally in all subroutines. However, a brief, functional description of each subroutine appears below. An examination of the listing in Table D-4 will reveal that many "PRINT" statements have been rendered inactive by a "C" in Column 1. These statements are rarely used after familiarity is gained with the overall program. The inactive statements have been retained in the listing to provide potential users with tools which can be used to follow the detailed flow of the CFLOS analysis. Reactivation of all "PRINT" statements will produce a computer printout about 4 inches thick. If wholesale reactivation is desired, we recommend using BCFLOS as the driver program since it is set up to produce only a single cloud distribution and to "fly through" only once.

SET Initializes required values within other subroutines.

CLDNO Contains only one entry: Entry CLOUDNO. CLOUDNO establishes the positions of the centers of each cloud and a percentage coverage. The cloud center coordinates are generated using a random number generator. Cloud elements will not overlap.

CLDOVR Contains a single entry, CLOUDNO, which allows a newly introduced element to overlap one existing element up to a limit equal to the cloud radius. This entry should be used for coverages in excess of about 45%.

HUNTF Contains two different entries:

a. Entry HUNT produces the positions of two moving objects (A,B) whose initial positions have been specified in the driver program. The dynamics of this entry are such as might correspond to an IR Sensor tracking a moving object. In essence, A continually heads toward the current position of B.

b. Entry HUNTD is a slightly more sophisticated chase routine (see Appendix A) in which the point toward which A must move to intercept B is predetermined, based on the assumption that B will continue on a straight-line course at a constant speed.

Output from both of these entries includes x,y,z coordinates, the slant range distance between A and B, and the elevation angle from B to A, all as a function of time. The parameters are no longer calculated after a predetermined time and/or slant range has been reached. LIMA and LIMB are used to indicate that the elevation angle has exceeded certain boundaries, in the case of LIMA, or that both vehicles are below the base of the cloud (LIMB). Although not currently used, these indicators are useful diagnostic tools.

FREEF Contains only Entry FREE. FREE uses the positional information derived from either HUNT or HUNTD to examine the line-of-sight to ascertain whether or not it intercepts any clouds. If it intercepts any cloud it is determined to be obscured; otherwise a CFLOS "hit" is recorded.

MAPF & CATCH These are the "bookkeeping" and "statistics gathering" subroutines.

Table D-1. Listing of BCFLOS.

```
      PROGRAM BCFLOS%INPUT,OUTPUT<
C     THIS PROGRAM WAS DESIGNED TO EXAMINE THE TIME HISTORY OF THE CLOUD
C     OBSTRUCTED OR CLOUD FREE LINE OF SIGHT BETWEEN TWO OBJECTS MOVING
C     IN THE PRESENCE OF A CLOUD FIELD. THE USER MUST SPECIFY THE
C     INITIAL CONDITIONS  AND DECIDE ON ONE OF TWO CHASE MODELS AND ONE
C     OF TWO CLOUD MODELS TO BE USED IN THE ANALYSIS. AERIAL COVERAGE OF
C     THE CLOUD IS DETERMINED BY THE FRACTION OF THE UNDERLYING SURFACE
C     COVERED BY THE PROJECTION OF THE CLOUD BASES.
      COMMON /BLK1/ XCLD%1000<,YCLD%1000<,JJ
      COMMON /BLK2/ PXA%100<,PYA%100<,PZA%100<,PXB%100<,PYB%100<,PZB%100
     1<,TAB%100<,DAB%100<,KK
      COMMON /BLK3/ AZA,AZB,EL,XBI,YBI,ZBI,DI,VA,VB
      COMMON /BLK4/ KLN%200<,KL,LIMA%4<,LIMB%4<
      COMMON /BLK5/ CLDB
      COMMON /BLK6/ J
      COMMON /BLK7/ BCLD,TCLD,PCVR,RAD,HOR
C     ESTABLISH INITIAL CONDITIONS
C           Z # VERTICAL SEPARATION OF THE TWO OBJECTS
C           DI # INITIAL SLANT RANGE DISTANCE
C           EL # ELEVATION ANGLE FROM THE SLOWER %B< TO THE FASTER %A<
C     OBJECT.
C           XBI,YBI,ZBI # INITIAL POSITION OF B.
C           VA,VB # SPEEDS OF A AND B.  VA MUST BE GREATER THAN VB.
C           RAD # RADIUS OF CLOUD ELEMENTS/100.
C           HOR # RADIUS OF REGION OVER WHICH CLOUDS ARE EMPLACED.
C           PCVR # PERCENT OF COVERAGE DESIRED.
C           BCLD,TCLD # BASE AND TOP OF CLOUD ELEMENTS/100.
      Z#5000./3.28
      DI#4000.
      Y#Z/DI
      EL#ASIN%Y<
      EL#EL*180./3.1416
      XBI#YBI#0.
      ZBI#150.
      VA#1000.
      VB#250.
      HOR#5000.
      PCVR#.3
      RAD#4.
      BCLD#4.
      TCLD#9.
      CALL SET
C     DECIDE ON USING AN OVERLAPPING CLOUD FIELD %CLOUDO< OR A
C     NON-OVERLAPPING FIELD %CLOUDNO<. CLOUDO IS RECOMMENDED FOR
C     COVERAGES OF .50 OR GREATER.
      CALL CLOUDNO
      CALL CATCH1
      CALL GILO
      DO 1 J#1,12
      AZB#30.0*%J-1<
      CALL CLR
      AZA#AZB&25.0
```

Table D-1. Listing of BCFLOS (Cont'd).

```
C     DECIDE ON A DIRECT INTERCEPT %HUNTD< OR TAIL CHASING %HUNT<
C     SCENARIO.
      CALL HUNTD
      KK#KK-1
      CALL CLRX
      CALL FREE
      AZA#AZB-25.0
      CALL HUNTD
      KK#KK-1
      CALL CLRX
      CALL FREE
      CALL GIL1
    1 CONTINUE
      CALL GIL2
C     ***PCVR IS RESET TO THE ACTUAL COVERAGE ATTAINED IN THE CLOUD
C     SUBROUTINE. SETTING COVER # PCVR OBTAINS THIS VALUE FOR PRINTOUT
C     PURPOSES.***
      COVER#PCVR
      PRINT 2, BCLD,TCLD,RAD,COVER
C
    2 FORMAT %//,10X,29HABOVE INFO BASED ON - BASE # ,F5.1,8H,TOPS # ,F5
     1.1,11H ,RADIUS # ,F5.1,13H ,COVERAGE # ,F6.3<
      END
```

Table D-2. Listing of LOSØAZ.

```
      PROGRAM LOSOAZ%INPUT,OUTPUT<
C     THIS PROGRAM WAS DESIGNED TO EXAMINE THE TIME HISTORY OF THE CLOUD
C     OBSTRUCTED OR CLOUD FREE LINE OF SIGHT BETWEEN TWO OBJECTS MOVING
C     IN THE PRESENCE OF A CLOUD FIELD.  THE USER MUST SPECIFY THE
C     INITIAL CONDITIONS  AND DECIDE ON ONE OF TWO CHASE MODELS TO BE
C     USED IN THE ANALYSIS. THIS PROGRAM IS TO BE USED ONLY WITH  NON-
C     OVERLAPPING CLOUD FIELDS.
C     AERIAL COVERAGE OF THE CLOUD IS DETERMINED BY THE FRACTION OF THE
C     UNDERLYING SURFACE COVERED BY THE PROJECTION OF THE CLOUD BASES.
      COMMON /BLK1/ XCLD%1000<,YCLD%1000<,JJ
      COMMON /BLK2/ PXA%100<,PYA%100<,PZA%100<,PXB%100<,PYB%100<,PZB%100
     1<,TAB%100<,DAB%100<,KK
      COMMON /BLK3/ AZA,AZB,EL,XBI,YBI,ZBI,DI,VA,VB
      COMMON /BLK4/ KLN%200<,KL,LIMA%4<,LIMB%4<
      COMMON /BLK5/ CLDB
      COMMON /BLK6/ J
      COMMON /BLK7/ BCLD,TCLD,PCVR,RAD,HOR
C     ESTABLISH INITIAL CONDITIONS
C           Z # VERTICAL SEPARATION OF THE TWO OBJECTS
C           DI # INITIAL SLANT RANGE DISTANCE
C           EL # ELEVATION ANGLE FROM THE SLOWER %B< TO THE FASTER %A<
C     OBJECT.
C           XBI,YBI,ZBI # INITIAL POSITION OF B.
C           VA,VB # SPEEDS OF A AND B.  VA MUST BE GREATER THAN VB.
C           RAD # RADIUS OF CLOUD ELEMENTS DIVIDED BY 100.
C           HOR # RADIUS OF REGION OVER WHICH CLOUDS ARE EMPLACED.
C           PCVR # PERCENT OF COVERAGE DESIRED.
C           BCLD,TCLD # BASE AND TOP OF CLOUD ELEMENTS DIVIDED BY 100.
      Z#5000./3.28
      DI#4000.
      Y#Z/DI
      EL#ASIN%Y<
      EL#EL*180./3.1416
      XBI#YBI#0.
      ZBI#150.
      VA#750.
      VB#250.
      HOR#5000.
      FLAG#0
    1 CONTINUE
      FLAG#FLAG&1
      KKK#0
      PCVR#.5
      RAD#4.
    2 CONTINUE
      BCLD#4.
      TCLD#9.
    3 CONTINUE
      THCLD#TCLD-BCLD
      DO 6 M#1,2
C     CHANGE THICKNESS OF CLOUD WITHOUT CHANGING BASE OR POSITION OF
C     ELEMENT. ***
      TCLD#TCLD&%M-1<*THCLD/2.
      IF %M.GT.1< GO TO 4
      IF %KKK.GT.0< GO TO 4
      CALL SET
C     USE A NON-OVERLAPPING CLOUD FIELD ONLY.
C     DO NOT CALL CLOUDO WITH THIS PROGRAM.
      CALL CLOUDNO
```

Table D-2. Listing of LOSØAZ (Cont'd).

```
    4 CONTINUE
      CALL CATCH1
      CALL GILO
      DO 5 J#1,12
      AZB#30.0*%J-1<
      CALL CLR
      AZA#AZB&25.0
C     DECIDE ON A DIRECT INTERCEPT %HUNTD< OR TAIL CHASING %HUNTC<
C     SCENARIO.
      CALL HUNTD
      KK#KK-1
      CALL CLRX
      CALL FREE
      AZA#AZB-25.0
      CALL HUNTD
      KK#KK-1
      CALL CLRX
      CALL FREE
      CALL GIL1
    5 CONTINUE
      CALL GIL2
      COVER#JJ*%RAD*100.<**2./%HOR**2.<
      PRINT 10, BCLD,TCLD,RAD,COVER
    6 CONTINUE
      KKK#KKK&1
C     CHANGE BASES OF CLOUD WITHOUT CHANGING THE POSITION OF THE
C     ELEMENTS.
      BCLD#BCLD&1.5
      IF %KKK.GT.2< GO TO 7
      GO TO 3
C     CHANGE THE RADIUS %AND THEREFORE COVERAGE< WITHOUT CHANGING THE
C     POSITION OF THE ELEMENTS. THIS WORKS ONLY WITH CLOUDNO.
    7 RAD#3.
      IF %KKK.GT.3< GO TO 8
      GO TO 2
    8 CONTINUE
      GO TO %1,9<, FLAG
    9 CONTINUE
C
   10 FORMAT %//,10X,29HABOVE INFO BASED ON - BASE # ,F5.1,8H ,TOPS # ,F5
     1.1,11H ,RADIUS # ,F5.1,13H ,COVERAGE # ,F6.3<
      END
```

Table D-3. Listing of LOS1AZ.

```
      PROGRAM LOS1AZ%INPUT,OUTPUT<
C     THIS PROGRAM WAS DESIGNED TO EXAMINE THE TIME HISTORY OF THE CLOUD
C     OBSTRUCTED OR CLOUD FREE LINE OF SIGHT BETWEEN TWO OBJECTS MOVING
C     IN THE PRESENCE OF A CLOUD FIELD. THE USER MUST SPECIFY THE
C     INITIAL CONDITIONS  AND DECIDE ON ONE OF TWO CHASE MODELS AND ONE
C     OF TWO CLOUD MODELS TO BE USED IN THE ANALYSIS. AERIAL COVERAGE OF
C     THE CLOUD IS DETERMINED BY THE FRACTION OF THE UNDERLYING SURFACE
C     COVERED BY THE PROJECTION OF THE CLOUD BASES.
      COMMON /BLK1/ XCLD%1000<,YCLD%1000<,JJ
      COMMON /BLK2/ PXA%100<,PYA%100<,PZA%100<,PXB%100<,PYB%100<,PZB%100
     1<,TAB%100<,DAB%100<,KK
      COMMON /BLK3/ AZA,AZB,EL,XBI,YBI,ZBI,DI,VA,VB
      COMMON /BLK4/ KLN%200<,KL,LIMA%4<,LIMB%4<
      COMMON /BLK5/ CLDB
      COMMON /BLK6/ J
      COMMON /BLK7/ BCLD,TCLD,PCVR,RAD,HOR
C     ESTABLISH INITIAL CONDITIONS
C          Z # VERTICAL SEPARATION OF THE TWO OBJECTS
C          DI # INITIAL SLANT RANGE DISTANCE
C          EL # ELEVATION ANGLE FROM THE SLOWER %B< TO THE FASTER %A<
C     OBJECT.
C          XBI,YBI,ZBI # INITIAL POSITION OF B.
C          VA,VB # SPEEDS OF A AND B.  VA MUST BE GREATER THAN VB.
C          RAD # RADIUS OF CLOUD ELEMENTS/100.
C          HOR # RADIUS OF REGION OVER WHICH CLOUDS ARE EMPLACED.
C          PCVR # PERCENT OF COVERAGE DESIRED.
C          BCLD,TCLD # BASE AND TOP OF CLOUD ELEMENTS/100.
      Z#5000./3.28
      DI#4000.
      SR#DI
      Y#Z/SR
      EL#ASIN%Y<
      EL#EL*180./3.1416
      XBI#YBI#0.
      ZBI#150.
      VA#750.
      VA#1000.
      VB#250.
      HOR#5000.
      FLAG#0
    1 CONTINUE
      FLAG#FLAG&1
      KKK#0
      PCVR#.7
      RAD#3.
      BCLD#4.
      BCLD#2.5
      TCLD#9.
      TCLD#5.
    2 CONTINUE
      THCLD#TCLD-BCLD
      DO 5 M#1,2
C     CHANGE THICKNESS OF CLOUD WITHOUT CHANGING BASE OR POSITION OF
C     ELEMENTS. ***
      TCLD#TCLD&%M-1<*THCLD/2.
      IF %M.GT.1< GO TO 3
      IF %KKK.GT.0< GO TO 3
      CALL SET
C     DECIDE ON USING AN OVERLAPPING CLOUD FIELD %CLOUDO< OR A
C     NON-OVERLAPPING FIELD %CLOUDNO<. CLOUDO IS  RECOMMENDED FOR
C     COVERAGES OF .50 OR GREATER.
      CALL CLOUDO
```

Table D-3. Listing of LOS1AZ (Cont'd).

```
      3 CONTINUE
        CALL CATCH1
        CALL GILO
        DO 4 J#1,12
        AZB#30.0*%J-1<
        CALL CLR
        AZA#A7B&25.0
        AZA#AZB&155.
C       DECIDE ON A DIRECT INTERCEPT %HUNTD< OR TAIL CHASING %HUNTC<
C       SCENARIO.
        CALL HUNTD
        KK#KK-1
        CALL CLRX
        CALL FREE
        AZA#AZB-25.0
        AZA#AZB-155.
        CALL HUNTD
        KK#KK-1
        CALL CLRX
        CALL FREE
        CALL GIL1
      4 CONTINUE
        CALL GIL2
        COVER#RCVR
        PRINT 8, BCLD,TCLD,RAD,COVER
      5 CONTINUE
        KKK#KKK&1
C       CHANGE BASES OF CLOUD WITHOUT CHANGING THE POSITION OF THE
C       ELEMENTS.
        BCLD#BCLD&1.5
        IF %KKK.GT.2< GO TO 6
        GO TO 2
      6 CONTINUE
        GO TO %1,7<, FLAG
      7 CONTINUE
C
      8 FORMAT %//,10X,29HABOVE INFO BASED ON - BASE # ,F5.1,8H,TOPS # ,F5
       1.1,11H ,RADIUS # ,F5.1,13H ,COVERAGE # ,F6.3<
        END
```

Table D-4. Listing of Subroutines.

```
      SUBROUTINE SET
C     THIS SUBROUTINE INITIALIZES REQUIRED OPERATING VALUES. ***
      CALL CLDNO
      CALL CLDOVR
      CALL HUNTF
      CALL FREEF
      CALL MAPF
      RETURN
      END
```

```
      SUBROUTINE CLDNO
C     THIS SUBROUTINE GENERATES THE CLOUD FIELD TO BE EXAMINED.******
C     *CLDNO PRODUCES A NON-OVERLAPPING CLOUD FIELD AND CAN BE USED
C     FOR COVERAGE UP TO ABOUT 45 PERCENT.  SUBROUTINE CLDOVR IS
C     RECOMMENDED FOR COVERAGES GREATER THAN 45 PERCENT.
      COMMON /BLK1/ XCLD%1000<,YCLD%1000<,JJ
      COMMON /BLK7/ BCLD,TCLD,PCVR,RAD,HOR
C     INITIALIZE*****
      SML#0.0001
      JJ#0
      JPSS#2000
      PY#3.1416$CDR#PY/180.0$CRD#1.0/CDR
      XRA#2.*%HOR-RAD*100.<$FRA#RAD*100.$DRA#2.*FRA
      CVR#PCVR$CLDS#0.0$BMP#PY*FRA**2
      TAR#PY*HOR**2
      CP#SECOND%CP<
      CALL RANSET %CP<
C     *************  END OF INITIALIZE  *******
      RETURN
      ENTRY CLOUDNO
      PRINT 7
    1 CONTINUE
C     ***  TEST FOR PERCENTA    LOUD COVER REACHED  *****
      PCNT#CLDS/TAR
      IF %PCNT.GT.CVR< GO TO 5
    2 CONTINUE
C       TEST FOR OVER 2000 PASSES  ***
      JPSS#JPSS-1
      IF %JPSS.LT.1< GO TO 5
      KPSS#2000-JPSS
C     ****  OBTAIN X AND Y COORDINATES FROM RANDOM NUM GEN ***
      RX#RANF%PY<$RY#RANF%PY<
      XP#RX*XRA-%HOR-RAD*100.<$YP#RY*XRA-%HOR-RAD*100.<
      RP#0.0$ARG#XP**2&YP**2
      IF %ARG.GT.SML< RP#SQRT%ARG<
C     **TEST FOR X AND Y WITHIN ACCEPTABLE LIMITS ***
      IF %RP.GT.%HOR-RAD*100.<< GO TO 2
C     TEST FOR OVERLAP ON OTHER CLOUDS.*****
      J#1
    3 CONTINUE
      IF %J.GT.JJ< GO TO 4
      XJ#XCLD%J<$YJ#YCLD%J<
      XT#XP-XJ$YT#YP-YJ$RT#0.0
      ARG#XT**2&YT**2
      IF %ARG.GT.SML< RT#SQRT%ARG<
      IF %RT.LT.DRA< GO TO 2
      J#J&1
      GO TO 3
```

Table D-4. Listing of Subroutines (Cont'd).

```
4       CONTINUE
C       *** X AND Y HAVE BEEN ACCEPTED ****
C       * STORE RESULTS ***UPDATE CLOUD COVER ***PRINT **
        JJ#JJ&1
        XCLD%JJ<#XP$YCLD%JJ<#YP
        CLDS#CLDS&BMP
C       PRINT 8,JJ,XP,RP,CLDS,PCNT,KPSS
        GO TO 1
5       CONTINUE
        PCVR#PCNT
        SCL#0.01
        DO 6 J#1,JJ
C       *  STORE SCALED VALUES OF THE CLOUD COORDINATES    ***
        XCLD%J<#XCLD%J<*SCL$YCLD%J<#YCLD%J<*SCL
6       CONTINUE
        PRINT 8,JJ,XP,YP,RP,CLDS,PCNT,KPSS
        RETURN
C
C
C
7       FORMAT %1H1/10X,2HJJ,11X,1HX,11X,1HY,11X,1HR,8X,4HCLDS,8X,4HPCNT,6
       1X,4HKPSS<
8       FORMAT %2X,I10,4F12.1,F12.3,I10<
        END
```

```
        SUBROUTINE CLDOVR
C        THIS SUBROUTINE PRODUCES A CLOUD FIELD WHICH ALLOWS FOR SOME
C       OVERLAPPING OF INDIVIDUAL ELEMENTS.  ANY NEWLY INTRODUCED ELEMENT
C       IS ALLOWED TO OVERLAP NO OTHER OR ONE OTHER CLOUD ELEMENT.  IF THE
C       NEWLY INTRODUCED ELEMENT WOULD OVERLAP TWO OR MORE EXISTING ELEMEN
C       IT IS REJECTED.  THE RESULT IS THAT STRINGS OF CLOUDS ARE POSSIBLE
C       BUT GROUPS OF MORE THAN TWO CLOUDS ARE NOT POSSIBLE.  ***
        COMMON /BLK1/ XCLD%1000<,YCLD%1000<,JJ
        COMMON /BLK7/ BCLD,TCLD,PCVR,RAD,HOR
C       ******INITIALIZE ******
        SML#0.0001
        JJ#0
        JPSS#MPSS#1000
        PY#3.1416$CDR#PY/180.0$CRD#1.0/CDR
        XRA#2.*%HOR-RAD*100.<
        ERA#RAD*100.
        DRA#2.*ERA
        CVR#PCVR
        BMP#PY*ERA**2.
        TAR#PY*HOR**2
        CLDS#0.0
        CP#SECOND%CP<
        CALL RANSET %CP<
C       *************  END OF INITIALIZE  *******
        RETURN
        ENTRY CLOUDO
        PRINT 9
1       CONTINUE
C       $$$ TEST FOR PERCENTAGE CLOUD COVER REACHED.   $$$$
        PCNT#CLDS/TAR
        IF %PCNT.GT.CVR< GO TO 6
```

Table D-4. Listing of Subroutines (Cont'd).

```
2     CONTINUE
C     **  TEST FOR OVER 1000 PASSES  ****
      JPSS#JPSS-1
      IF %JPSS.LT.1< GO TO 6
      KPSS#MPSS-JPSS
C     ****  OBTAIN X AND Y COORDINATES FROM RANDOM NUM GEN ***
      RX#RANF%PY<$RY#RANF%PY<
      XP#RX*XRA-%HOR-RAD*100.<
      YP#RY*XRA-%HOR-RAD*100.<
      RP#0.0$ARG#XP**2&YP**2
      IF %ARG.GT.SML< RP#SQRT%ARG<
C     **TEST FOR X AND Y WITHIN ACCEPTABLE LIMITS ***
      IF %RP.GT.%HOR-RAD*100.<< GO TO 2
C     *TEST FOR OVERLAP ON OTHER CLOUDS. ***
      J#1
      KBMP#1
      BMPX#BMP
3     CONTINUE
      IF %J.GT.JJ< GO TO 5
      XJ#XCLD%J<$YJ#YCLD%J<
      XT#XP-XJ$YT#YP-YJ$RT#0.0
      ARG#XT**2&YT**2
      IF %ARG.GT.SML< RT#SQRT%ARG<
      IF %RT.LT.DRA< GO TO 8
4     CONTINUE
      J#J&1
      GO TO 3
5     CONTINUE
C     *** X AND Y HAVE BEEN ACCEPTED ****
C     * STORE RESULTS ***UPDATE CLOUD COVER ***PRINT **
      JJ#JJ&1
      XCLD%JJ<#XP$YCLD%JJ<#YP
      CLDS#CLDS&BMPX
      GO TO 1
6     CONTINUE
      PCVR#PCNT
      SCL#0.01
      DO 7 J#1,JJ
      XCLD%J<#XCLD%J<*SCL$YCLD%J<#YCLD%J<*SCL
7     CONTINUE
      PRINT 10, JJ,XP,YP,RP,CLDS,PCNT,KPSS
      RETURN
```

Table D-4. Listing of Subroutines (Cont'd).

```
8     CONTINUE
C     TEST FOR OVERLAP ON MORE THAN ONE ELEMENT.  REJECT IF THE NEW
C     ELEMENT OVERLAPS MORE THAN ONE OTHER ELEMENT, OR IF IT OVERLAPS
C     BY A DISTANCE GREATER THAN THE RADIUS OF THE OVERLAPPED ELEMENT.**
      IF %RT.LT.FRA< GO TO 2
      IF %KBMP.LT.1< GO TO 2
C     *DETERMINE THE ADDITIONAL COVERAGE INDUCED BY THE POTENTIALLY
C     ACCEPTABLE NEW ELEMENT.  NOTE THAT THE ADDITIONAL COVERAGE WILL NO
C     BE USED IF A MOVE IS MADE TO ADDRESS 2 BEFORE A MOVE IS MADE TO
C     ADDRESS 5. ***
      D1#RT
      D2#DRA-D1
      D3#ERA-D2/2.0
      D4#0.0$ARG#FRA**2-D3**2
      IF %ARG.GT.SML< D4#SQRT%ARG<
      ARG#D4/DRA
      ARG#D4/DRA$ANG#2.0*ASIN%ARG<
      RAT#ANG/%2.0*PY<
      A1#D3*D4/2.0$A2#RAT*BMP$A3#2.0*%A2-A1<
      BMPX#BMPX-A3
      KBMP#KBMP-1
      GO TO 4
C
C
C
9     FORMAT %1H1/10X,2HJJ,11X,1HX,11X,1HY,11X,1HR,8X,4HCLDS,8X,4HPCNT,6
     1X,4HKPSS<
10    FORMAT %2X,I10,4F12.1,F12.3,I10<
      END
```

```
      SUBROUTINE HUNTF
C     * THIS SUBROUTINE DETERMINES THE PORTIONS OF THE VEHICLES IS
C     A FUNCTION OF SIMULATED TIME. ***
      COMMON /BLK2/ PXA%100<,PYA%100<,PZA%100<,PXB%100<,PYB%100<,PZB%100
     1<,TAB%100<,DAB%100<,KK
      COMMON /BLK3/ AZA,AZB,EL,XBL,YBL,ZBL,DL,VA,VB
      COMMON /BLK4/ KLN%200<,KL,LIMA%4<,LIMB%4<
      COMMON /BLK5/ CLDB
      COMMON /BLK6/ J
      COMMON / LK7/ BCLD,TCLD,PCVR,RAD,HOR
C     INITIALIZE.*****
      SML#0.00001
      PY#3.1416$CDR#PY/180.0$CRD#1.0/CDR
C     END OF INITIALIZE.*****
      RETURN
      ENTRY HUNTD
```

Table D-4. Listing of Subroutines (Cont'd).

```
C      DETERMINE POSITIONS FOR DIRECT INTERCEPT MODEL USING TIME STEPS OF
C      0.2 SECONDS.  NOTE THAT IN THIS MODEL THE ELEVATION ANGLE REMAINS
C      CONSTANT. ***
       PHI#EL
C      PRINT 13,AZA,AZB,EL,DI,ZBI
       A#COR*AZB$VXB#COS%A<*VB$VYB#SIN%A<*VB
       A#COR*AZA$E#COR*EL
       XAI#DI*COS%E<*COS%A<
       YAI#DI*COS%E<*SIN%A<
       ZAI#DI*SIN%E<&ZBI
       XA#XAI$YA#YAI$ZA#ZAI
       XB#XBI$YB#YBI$ZB#ZBI$D#DI
       CLDB#BCLD
       KPSS#0
       TM#0.0
       JTM#0$JDLT#20
       DT#JDLT/100.0
       KK#0
C      PRINT 11
       KFLAG#0
       KF#KL/50&1
C      DETERMINE THE FINAL X,Y POSITION OF THE VEHICLES.***
       A#COR*AZB
       DUM1#COS%A<*%XA&YA*TAN%A<<
       DUM2#%VA**2/VB**2<-1.
       DB#%-DUM1&SQRT%DUM1**2&DUM2*DI**2<</DUM2
       XF#DB*COS%A<
       YF#DB*SIN%A<
       DA#SQRT%%XF-XA<**2&%YF-YA<**2&%ZB-ZA<**2<
       P#%XF-XA</DA$Q#%YF-YA</DA$R#%ZB-ZA</DA
1      CONTINUE
C      DETERMINE POSITIONS OF A AND B, FOR THE FINAL POSITION JUST CALCUL
C      ATED, EVERY 0.2 SECONDS.*****
       KK#KK&1
       PXA%KK<#XA$PYA%KK<#YA$PZA%KK<#ZA
       PXB%KK<#XB$PYB%KK<#YB$PZB%KK<#ZB
       TAB%KK<#TM$DAB%KK<#D
C      PRINT 12,KPSS,TM,XA,YA,ZA,XB,YB,ZB,D,PHI
       IF %KFLAG.EQ.1< GO TO 2
C      IF A HAS REACHED BASE OF CLOUDS, FLAG THIS POSITION
       IF %ZA.LT.CLDB*100.< GO TO 3
2      CONTINUE
       KPSS#KPSS&1
       IF %KPSS.GT.100< GO TO 4
C      IF SLANT RANGE IS LESS THAN 501 UNITS, STOP.*****
C      SAVE THIS POSITION.*****
       IF %D.LT.501.0< GO TO 4
       JTM#JTM&JDLT$TM#JTM$TM#TM/100.0
       IF %TM.GT.9.0< GO TO 4
       VXA#VA*P$VYA#VA*Q$VZA#VA*R
       XA#XA&VXA*DT$YA#YA&VYA*DT$ZA#ZA&VZA*DT
       XB#XB&VXB*DT$YB#YB&VYB*DT$ZB#ZB
       D#0.0
       ARG#%XB-XA<**2&%YB-YA<**2&%ZB-ZA<**2
       IF %ARG.GT.SML< D#SQRT%ARG<
       GO TO 1
3      LIMB%KM<#KK-1
       KFLAG#1
       GO TO 2
```

Table D-4. Listing of Subroutines (Cont'd).

```
4       IF %LIMA%KM<.LE.1< LIMA%KM<#KK
        IF %LIMB%KM<.LE.1< LIMB%KM<#KK
        SCL#0.01
C       SCALE THE POSITION VALUES. ***
        DO 5 K#1,KK
        PXA%K<#PXA%K<*SCL$PYA%K<#PYA%K<*SCL
        PZA%K<#PZA%K<*SCL$PXB%K<#PXB%K<*SCL
        PYB%K<#PYB%K<*SCL$PZB%K<#PZB%K<*SCL
        DAB%K<#DAB%K<*SCL
5       CONTINUE
        RETURN
        ENTRY HUNT
C       THIS ENTRY DETERMINES THE POSITIONS OF THE TWO VEHICLES WHEN A
C       ALWAYS HEADS TOWARD THE CURRENT POSITION OF B. ***
C       PRINT 13,AZA,AZB,EL,DI,ZBI
        CLDB#BCLD
        A#CDR*AZB$VXB#COS%A<*VB$VYB#SIN%A<*VB
        A#CDR*AZA$E#CDR*EL
        XAI#DI*COS%E<*COS%A<
        YAI#DI*COS%E<*SIN%A<
        ZAI#DI*SIN%E<
        XA#XAI$YA#YAI$ZA#ZAI
        XB#XBI$YB#YBI$ZB#ZBI$D#DI
        KPSS#0
        PHI#EL
        TM#0.0
        JTM#0$JDLT#20
        DT#JDLT/100.0
        KK#0
C       PRINT 11
        KFLAG#LFLAG#0
C       ESTABLISH THE BOUNDS WITHIN WHICH STATISTICS WILL BE COLLECTED. **
        UPPER#EL&5.
        LOWER#EL-5.
        KM#KL/50&1
6       CONTINUE
C       DETERMINE THE POSITIONS OF A AND B. ***
        KK#KK&1
        PXA%KK<#XA$PYA%KK<#YA$PZA%KK<#ZA
        PXB%KK<#XB$PYB%KK<#YB$PZB%KK<#ZB
        TAB%KK<#TM$DAB%KK<#D
        IF %KFLAG.EQ.1< GO TO 7
C       IF A HAS REACHED THE BASE OF THE CLOUDS, FLAG THIS POSITION. ***
        IF %ZA.LT.CLDB*100.< GO TO 8
7       CONTINUE
C       PRINT 12,KPSS,TM,XA,YA,ZA,XB,YB,ZB,D,PHI
        KPSS#KPSS&1
C       IF THE SLANT RANGE DISTANCE IS LESS THAN 501 UNITS,OR IF THE
C       SIMULATED TIME HAS EXCEEDED 9 SECONDS, STOP. ***
        IF %KPSS.GT.90< GO TO 9
        IF %D.LT.501.0< GO TO 9
        JTM#JTM&JDLT$TM#JTM$TM#TM/100.0
        IF %TM.GT.9.0< GO TO 9
        P#%XB-XA</D$Q#%YB-YA</D$R#%ZB-ZA</D
        VXA#VA*P$VYA#VA*Q$VZA#VA*R
        XA#XA&VXA*DT$YA#YA&VYA*DT$ZA#ZA&VZA*DT
        XB#XB&VXB*DT$YB#YB&VYB*DT$ZB#ZB
```

Table D-4. Listing of Subroutines (Cont'd).

```
C     DETERMINE THE CURRENT ELEVATION ANGLE. ***
      D#0.0
      ARG#%XB-XA<**2&%YB-YA<**2&%ZB-ZA<**2
      IF %ARG.GT.SML< D#SQRT%ARG<
      PHI#ATAN2%R,SQRT%P**2&Q**2<<
      PHI#-PHI*CRD
      IF %LFLAG.EQ.1< GO TO 6
C     IF THE ELEVATION ANGLE HAS EXCEEDED THE ANGULAR LIMITS ESTABLISHED
C     FLAG THIS POSITION. ***
      IF %PHI.LT.UPPER.A.PHI.GT.LOWER< GO TO 6
      LIMA%KM<#KK
      LFLAG#1
      GO TO 6
8     LIMB%KM<#KK-1
      KFLAG#1
      GO TO 7
9     IF %LIMA%KM<.LE.1< LIMA%KM<#KK
      IF %LIMB%KM<.LE.1< LIMB%KM<#KK
C     SCALE THE POSITION VALUES. ***
      SCL#0.01
      DO 10 K#1,KK
      PXA%K<#PXA%K<*SCL$PYA%K<#PYA%K<*SCL
      PZA%K<#PZA%K<*SCL$PXB%K<#PXB%K<*SCL
      PYB%K<#PYB%K<*SCL$PZB%K<#PZB%K<*SCL
      DAB%K<#DAB%K<*SCL
10    CONTINUE
      RETURN
C
C
      END
```

```
      SUBROUTINE FREEF
C     THIS SUBROUTINE USES THE POSITIONAL INFORMATION PRODUCED IN EITHER
C     HUNT OR HUNTD AND THE CLOUD INFORMATION GENERATED BY EITHER CLDNO
C     OR CLDOVR TO DETERMINE THE HISTORY OF THE CELOS BETWEEN A AND B. *
      COMMON /BLK1/ XCLD%1000<,YCLD%1000<,JJ
      COMMON /BLK2/ PXA%100<,PYA%100<,PZA%100<,PXB%100<,PYB%100<,PZB%100
     1<,TAB%100<,DAB%100<,KK
      COMMON /BLK4/ KLN%200<,KL,LIMA%4<,LIMB%4<
      COMMON /BLK5/ CLDB
      COMMON /BLK6/ J
      COMMON /BLK7/ BCLD,TCLD,PCVR,RAD,HOR
C     INITIALIZE ***
      PY#3.1416$CDR#PY/180.0$CRD#1.0/CDR
      SML#0.00001
      CR#RAD$CZ#2.*CR
      SMLH#0.01
      KBLNK#1R
      KX#1RX
C     END OF INITIALIZE. ***
      RETURN
      ENTRY FREE
      CLDB#BCLD$CLDT#TCLD
      JFLG#KFLG#0
      CR#RAD$CZ#2.*CR
      KNT#0
      K#0
```

Table D-4. Listing of Subroutines (Cont'd).

```
1     CONTINUE
      KNI#KNI&1
      JC#1
C     ******  SHIFT ORIGIN TO AX,AY AND ROTATE AXES FOR BY#0  ****
C     SLOPE#H/D      *****
      K#K&1
      IF %K.GT.KK< GO TO 17
      AX#PXA%K<$AY#PYA%K<$ALVL#PZA%K<
      BX#PXB%K<$BY#PYB%K<$BLVL#PZB%K<
      H#BY-AY$D#BX-AX$R#SQRT%H**2&D**2<
      SGN#1.0$IF %D.LT.0<SGN#-1.0
      IF %ABS%D<.LT.SMLH< D#SGN*SMLH
      SLP#H/D
      SLPZ#%BLVL-ALVL</R
      ANG#ATAN2%H,D<$DGRS#ANG*CRD
      CSNA#COS%ANG<$FSNA#SIN%ANG<
C     ***********  ROTATION EQUATIONS  *****
C     XP#%Y-AY<*FSNA&%X-AX<*CSNA       ********
C     YP#%Y-AY<*CSNA-%X-AX<*FSNA
C     ***************                ************        ******
C     PRINT 26
      KN#KNI-1
C     PRINT 25,KN,TAB%K<,PXA%K<,PYA%K<,PZA%K<,PXB%K<,PYB%K<,PZB%K<,DAB%
C    1K<,K
C     TEST FOR A AND B ABOVE OR BELOW CLOUD FIELD
      IF %ALVL.GT.CLDB< GO TO 2
      IF %BLVL.GT.CLDB< GO TO 2
C     A AND B ARE BOTH BELOW CLOUDS
      GO TO 11
2     CONTINUE
      IF %ALVL.LT.CLDT< GO TO 3
      IF %BLVL.LT.CLDT< GO TO 3
C     A AND B ARE BOTH ABOVE CLOUDS
      GO TO 11
3     CONTINUE
4     CONTINUE
      CX#XCLD%JC<$CY#YCLD%JC<
      TRM1#CY-AY$TRM2#CX-AX
      X#TRM1*FSNA&TRM2*CSNA
      Y#TRM1*CSNA-TRM2*FSNA
C     TEST FOR CLD BETWEEN A AND B
      IF %X.LT.-CR< GO TO 5
      IF %X.GT.%R&CR<< GO TO 6
C     CLOUD IS LOCATED BETWEEN A AND B
C     *** TEST FOR A INSIDE CYL BASE
      RT#0.0
      ARG#X**2&Y**2
      IF %ARG.GT.SML< RT#SQRT%ARG<
      IF %RT.LT.CR< GO TO 12
C     * TEST FOR B INSIDE CYL BASE
      XT#X-R$YT#Y$RT#0.0
      ARG#XT**2&YT**2
      IF %ARG.GT.SML< RT#SQRT%ARG<
      IF %RT.LT.CR< GO TO 13
C     TEST FOR LOS INTERCEPT OF CLD PROJCTN ON THE XY PLANE
      ABY#ABS%Y<
      IF %ABY.LT.CR< GO TO 7
5     CONTINUE
      JC#JC&1
      IF %JC.LT.JJ< GO TO 4
      GO TO 11
```

Table D-4. Listing of Subroutines (Cont'd).

```
6     CONTINUE
C     LOS NOT OBSCURED BY CURRENT CLOUD
      GO TO 5
7     CONTINUE
C     LOS INTERCEPT OF CLD PRJCTN ON THE XY PLANE
C     TEST FOR LOS CLD INTERCEPT ON THE ZX PLANE
C     PRINT 22,JC
      STP#0.0$ARG#CR**2-Y**2
      IF %ARG.GT.SML< STP#SQRT%ARG<
      X1#X-STP$X2#X&STP
      Z1#ALVL&SLPZ*X1$Z2#ALVL&SLPZ*X2
8     CONTINUE
C     TEST FOR Z1 AND Z2 BOTH LESS THAN CLD BASE
      IF %Z1.GT.CLDB< GO TO 9
      IF %Z2.GT.CLDB< GO TO 9
C     Z1 AND Z2 ARE BOTH LESS THAN CLD BASE
      GO TO 5
9     CONTINUE
C     TEST FOR Z1 AND Z2 BOTH GREATER THAN CLOUD TOP. ***
      IF %Z1.LT.CLDT< GO TO 10
      IF %Z2.LT.CLDT< GO TO 10
C     Z1 AND Z2 ARE BOTH GREATER THAN CLOUD TOP
      GO TO 5
10    CONTINUE
C     LOS IS OBSCURED *** OBTAIN NEXT SET OF A AND B
      KLN%KL&K<#KBLNK
C     PRINT 24,JC
      GO TO 14
11    CONTINUE
C     CLOUD FREE LINE OF SIGHT FOR CURRENT A AND B
C     PRINT 23,JC
      GO TO 14
12    CONTINUE
C     PT A FALLS WITHIN CLD PRJTN ON THE XY PLANE
C     PRINT 20,JC
C     TEST FOR LOS CLD INTERCEPT ON THE ZX PLANE
      Z1#ALVL
      STP#0.0$ARG#CR**2-Y**2
      IF %ARG.GT.SML< STP#SQRT%ARG<
      X2#X&STP
      Z2#ALVL&SLPZ*X2
      GO TO 8
13    CONTINUE
C     PT B FALLS WITHIN CLD PRJTN ON THE XY PLANE
C     PRINT 21,JC
C     TEST FOR LOS CLD INTERCEPT ON THE ZX PLANE
      Z2#BLVL$XP#X-R$YP#Y
      STP#0.0$ARG#CR**2-Y**2
      IF %ARG.GT.SML< STP#SQRT%ARG<
      B2#STP-XP
      Z1#BLVL-SLPZ*B2
      GO TO 8
14    CONTINUE
      IF %JFLG.GT.0< GO TO 15
      IF %DAB%K<.LT.5.1< GO TO 18
15    CONTINUE
      IF %KFLG.GT.0< GO TO 16
      IF %DAB%K<.LT.5.1< GO TO 19
16    CONTINUE
      GO TO 1
```

Table D-4. List of Subroutines (Cont'd).

```
 17     CONTINUE
        KL#KL&50
        RETURN
 18     CONTINUE
        JFLG#1
        KLN%KL&K<#KX
        GO TO 15
 19     CONTINUE
        KFLG#1
        KLN%KL&K<#KX
        GO TO 16
C
C
        END


        SUBROUTINE MAPF
C       THIS SUBROUTINE IS USED TO COLLECT CFLOS STATISTICS. ***
        COMMON /BLK1/ XCLD%1000<,YCLD%1000<,JJ
        COMMON /BLK2/ PXA%100<,PYA%100<,PZA%100<,PXB%100<,PYB%100<,PZB%100
       1<,TAB%100<,DAB%100<,KK
        COMMON /BLK3/ AZA,AZB,EL
        COMMON /BLK4/ KLN%200<,KL,LIMA%4<,LIMB%4<
        COMMON /BLK6/ J
        COMMON /BLK7/ BCLD,TCLD,PCVR,RAD,HOR
        COMMON /BLK8/ L,LIST,K,KILL%12,4<
        COMMON /BLKK/ KK1,KK2,KK3,KK4
        DIMENSION KOUNT%12<
        KDSH#1R-
C       INITIALIZE ***
        KBLNK#1R
        KX#1RX
C       END OF INITIALIZE. ***
        RETURN
C       BLANK THE CFLOS STORAGE ARRAY AND RETURN THE ANGULAR AND
C       CLOUD BASE POSITION FLAGS TO ZERO. ***
        ENTRY CLR
        KL#0
        DO 1 I#1,200
        KLN%I<#KBLNK
 1      CONTINUE
        DO 2 K#1,4
 2      LIMA%K<#LIMB%K<#0
        RETURN
        ENTRY CLRX
C       FILL THE CFLOS STORAGE FIELD WITH DASHES.  INSERT AN X PRINT AT
C       THE END OF THE FIELD. ***
        DO 3 I#1,KK
        KLN%KL&I<#KDSH
 3      CONTINUE
        K#KL&KK&1
        KLN%K<#KX
        RETURN
        ENTRY GIL0
C       ZERO THE CFLOS TOTAL-HITS FIELD. ***
        DO 4 L#1,12
 4      KOUNT%L<#0
        RETURN
        ENTRY GIL1
```

Table D-4. List of Subroutines (Cont'd).

```
C     COLLECT THE CFLOS STATISTICS. ***
      KA#KNTA#0
      L#J
      DO 6 K#1,2
      LTST#0
      KL#%K-1<*50
      DO 6 I#1,KK
      KTST#KLN%I&KL<
      IF %KTST.NE.KBLNK< GO TO 5
      LTST#0
      GO TO 6
C     COLLECT TIME-RELATED CFLOS STATISTICS.  KNTA IS USED TO COLLECT
C     INSTANTANEOUS HITS.  LTST IS USED FOR TIME-RELATED VALUES. ***
5     KNTA#KNTA&1
      LTST#LTST&1
      IF %LTST.GE.5< CALL CATCH2
6     CONTINUE
      KOUNT%L<#KNTA
      RETURN
      ENTRY GIL2
C     GATHER INSTANTANEOUS CFLOS STATISTICS. ***
      LSUM#0
      KSUM#KK
      DO 7 L#1,12
7     LSUM#LSUM&KOUNT%L<
      STATK#%LSUM*1.0</%KSUM*24.<
      PRINT 8, STATK
C     GATHER THE TIME-RELATED CFLOS STATISTICS. ***
      CALL GILCAT3
      RETURN
C
C
C
8     FORMAT %/,10X,37HPROBABILITY OF A CFLOS - STATIC CASE-,F9.3<
      END


      SUBROUTINE CATCH
C     THIS SUBROUTINE IS DESIGNED TO GATHER THE TIME-RELATED CFLOS
C     STATISTICS. ***
      COMMON /BLK3/ AZA,AZB,FL,XBI,YBI,ZBI,DI,VA,VB
      COMMON /BLK7/ BCLD,TCLD,PCVR,RAD,HOR
      COMMON /BLK8/ L,LTST,K,KLL%12,4<
      COMMON /BLK2/ PXA%100<,PYA%100<,PZA%100<,PXB%100<,PYB%100<,PZB%100
     1<,TAB%100<,DAB%100<,KK
      DIMENSION D5%12,4<, D10%12,4<, D15%12,4<, D20%12,4<, D25%12,4<, D3
     10%12,4<, D35%12,4<, D40%12,4<, D45%12,4<, F5%4<, F10%4<, F15%4<, F
     220%4<, F25%4<, F30%4<, L5%12,4<, L10%12,4<, L15%12,4<, L20%12,4<,
     3L25%12,4<, L30%12,4<, L35%12,4<, L40%12,4<, L45%12,4<
      RETURN
      ENTRY CATCH1
C     ZERO THE INDICATED ARRAYS. ***
      DO 1 K#1,4
      F5%K<#F10%K<#F15%K<#F20%K<#F25%K<#F30%K<#0.0
      DO 1 J#1,12
      D5%J,K<#D10%J,K<#D15%J,K<#D20%J,K<#D25%J,K<#D30%J,K<#D35%J,K<#D40%
     1J,K<#D45%J,K<#0.0
      L5%J,K<#L10%J,K<#L15%J,K<#L20%J,K<#L25%J,K<#L30%J,K<#L35%J,K<#L40%
     1J,K<#L45%J,K<#0
```

Table D-4. List of Subroutines (Cont'd).

```
1     CONTINUE
      RETURN
      ENTRY CATCH2
      IF %LTST.EQ.5< L5%L,K<#1
      D5%L,K<#D5%L,K<&1
      IF %LTST.LT.10< GO TO 2
      IF %LTST.EQ.10< L10%L,K<#1
      D10%L,K<#D10%L,K<&1
      IF %LTST.LT.15< GO TO 2
      IF %LTST.EQ.15< L15%L,K<#1
      D15%L,K<#D15%L,K<&1
      IF %LTST.LT.20< GO TO 2
      IF %LTST.EQ.20< L20%L,K<#1
      D20%L,K<#D20%L,K<&1
      IF %LTST.LT.25< GO TO 2
      IF %LTST.EQ.25< L25%L,K<#1
      D25%L,K<#D25%L,K<&1
      IF %LTST.LT.30< GO TO 2
      IF %LTST.EQ.30< L30%L,K<#1
      D30%L,K<#D30%L,K<&1
      IF %LTST.LT.35< GO TO 2
      IF %LTST.EQ.35< L35%L,K<#1
      D35%L,K<#D35%L,K<&1
      IF %LTST.LT.40< GO TO 2
      IF %LTST.EQ.40< L40%L,K<&1
      D40%L,K<#D40%L,K<&1
      IF %LTST.LT.45< GO TO 2
      IF %LTST.EQ.45< L45%L,K<#1
      D45%L,K<#D45%L,K<&1
2     CONTINUE
      RETURN
      ENTRY GILCAT3
C     GATHER STATISTICS ON ONE-SECOND AND TWO-SECOND LONG CFLOS
C     PROBABILITIES. ***
      K5#K10#0
      M5#KK-4
      M10#KK-9
      DO 3 J#1,12
      DO 3 K#1,2
      K5#K5&D5%J,K<
      K10#K10&D10%J,K<
3     CONTINUE
      S5#%K5*1.0</%24.*M5<
      S10#%K10*1.0</%24.*M10<
      PRINT 6
      PRINT 7, S5,S10
      LL5#LL10#0
      DO 5 K#1,2
      I#0
4     I#I&1
      IF %I.GT.12< GO TO 5
      LL5#LL5&L5%I,K<
      LL10#LL10&L10%I,K<
      GO TO 4
```

Table D-4. List of Subroutines (Cont'd).

```
5     CONTINUE
      PRINT 8
      PRINT 9, LL5,LL10
      RETURN
C
C
C
6     FORMAT (10X,54HPROBABILITY OF A CFLOS FOR AT LEAST THE TIME INDICA
     1TED<
7     FORMAT (10X,5H.GE.1,F8.3,10X,5H.GE.2,F8.3<
8     FORMAT (10X,74HMINIMUM FREQUENCY OF OCCURRENCE OF A CFLOS FOR AT L
     1EAST THE TIME INDICATED<
9     FORMAT (9X,10HONE SECOND,I9,3H/24,9X,11HTWO SECONDS,I9,3H/24<
      END
```

LIST OF TECHNICAL NOTES

Number	Title	Date
74-1	Atmospheric Moisture Parameterization (AD-784814)	Jan 74
74-2	Development of a Gridded Data Base ( ) (Publication delayed)	Apr 74
74-3	A Precipitating Convective Cloud Model (ADA-002117)	May 74
74-4	A Synoptic-Scale Model for Simulating Condensed Atmospheric Moisture (ADA-002118)	Jun 74
75-1	Estimated Improvement in Forecasts of the SANBAR Hurricane Model Using the Airborne Weather Reconnaissance System (ADA-004097)	Jan 75
75-2	Spring Weather Patterns of the Western United States (Reprints) (ADA-006691)	Mar 75
75-3	Summer Weather Patterns of the Western United States (Reprints) (ADA-009860)	May 75
75-4	Autumn Weather Patterns of the Western United States (Reprints) (ADA-013801)	Jul 75
75-6	Winter Weather Patterns of the Western United States (Reprints) (Publication delayed)	Sep 75
76-1	Listing of Seminars Available at Hq AWS, AWS Wings, and AFGWC (Publication delayed)	
76-2	Some Aspects of Estimating the Probability of Cloud-Free Lines-of-Sight in Dynamic Situations ( )	Mar 76